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Practical science and  
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Gerhard Feiner



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## Preface

Several years ago it became apparent to me that there was a need for an all-in-one book about meat processing which clearly outlined the parameters to be considered during the various steps of processing. However, in order to understand processing properly, the basic principles of meat science and the composition and function of additives have to be understood first. Therefore these would have to be covered in detail in the book as well.

The purpose of this book is to give clear and helpful guidelines to professionals within the meat-processing industry, such as technical, production, quality control and research and development managers. Butchers handling meat and meat products on a daily basis will also greatly benefit from it, as will undergraduate and postgraduate students, who will, I hope, find the book an invaluable tool for their studies.

Having worked all over the world in the meat-processing industry, conducting seminars for customers as well as lecturing at a university, I was often asked about the availability of such an all-in-one book. Books available today focus either on meat science or on manufacturing at various levels of detail but not on both at the same time. As such, this book combines a scientific and yet still hands-on approach and covers all three major aspects of meat technology. These are the raw materials themselves, the 'world' of additives and, finally, the technologies used to combine them. Microbiology related to meat and meat products is also discussed as it plays an integral role in the production process and in the safety and shelf life of meat and meat products.



## Acknowledgements

This book summarizes both my practical and my theoretical knowledge gained from working within the meat industry in several countries. My theoretical knowledge gained over the years is the result of both having been taught by and having worked with extremely knowledgeable people during my study of the Master Butcher Diploma and especially during my study of Meat Technology in Kulmbach (Germany). Therefore, I want to express deep gratitude to those who taught me over all those years, namely Titus Kaibic, Dipl.-Ing. Thomas Eberle, Dr Gerhard Hartmann, Dr Siegfried Guenther, Dr Fredi Schwaegele, Dr Guenther Hammer, Dipl.-Ing. Hans-Georg Hechelmann, Dr Klaus Fischer, Professor Lothar Leistner, Dr Herman Hecht, Professor Christoph Augustini, Dr Wolfgang Schneider, Dr Ulrike Fischer-Naegele, Dr Peter Braun, Dr Andrea Maurer, Udo Kuenzel, Barry Doesburg and Dr Joe Chen. I also want to thank all those people whom I no longer even remember who have given me ideas and help over the years. However the biggest thank you must go to my patient wife. She endured many lonely months whilst I wrote this book and has been a wonderful support during the research, writing and editing of the book.

During the course of my studies several books were of great help, namely: Breuer, H., *dtv-Atlas zur Chemie II: Organische Chemie und Kunststoffe*, 5th edition, Deutscher Taschenbuch Verlag, München, 1992.

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## **Disclaimer**

All information in this book is based on practical knowledge gained by the author whilst working in factories as well as theoretical knowledge gained during his studies and should not be used as the basis for any legal claims. Hence, all information stated is not intended to credit, or discredit, any manufacturer of equipment or additives and is based purely on the opinion of the author.



## Abbreviations

ADP	adenosine diphosphate
ATP	adenosine triphosphate
BHA	butylated hydroxyanisole
BHT	butylated hydroxytoluene
BSE	bovine spongiform encephalopathy
CCP	critical control point
cfu	colony-forming unit
CL	chemically lean
CJD	Creutzfeldt–Jakob disease
CoA	coenzyme A
CP	creatine phosphate
CU	colour unit
DE	dextrose equivalent
DFD	dark firm dry
DNA	deoxyribonucleic acid
ETC	electron transfer chain
FAD	flavin–adenine dinucleotide
FFA	free fatty acid
GDL	glucono- $\delta$ -lactone
GI	glycaemic index
GM	genetically modified
GMO	genetically modified organism
GTP	guanosine triphosphate
HACCP	hazard analysis critical control point
HDL	high-density lipoprotein
HLB	hydrophilic lipophilic balance
HVP	hydrolysed vegetable protein
IEP	isoelectric point
IgE	immunoglobulin E
IP	identity preserved
LBG	locust bean gum

xxii Abbreviations

LDL	low-density lipoprotein
3-MCPD	3-monochloropropane-1,2-diol
MDM	mechanically deboned meat
MEM	moisture-enhanced meat
MSG	monosodium glutamate
MSM	mechanically separated meat
NAD	nicotinamide adenine dinucleotide
NFSS	non-fermented sliceable salami
OSI	oxidative stability index
PAH	polycyclic aromatic hydrocarbon
PCR	polymerase chain reaction
PHM	pork head meat
PPP	post-pack pasteurization
PSE	pale soft exudative
PV	peroxide value
RH	relative humidity
RSE	red soft exudative
SF <sub>FM</sub>	solubility factor in fatty meat
SF <sub>M</sub>	solubility factor in lean meat
SMBS	sodium metabisulphite
SPR	sarcoplasmic reticulum
STPP	sodium tripolyphosphate
TBA	thiobarbituric acid
TG	transglutaminase
TPC	total plate count
TSC	trisodium citrate
TVP	textured vegetable protein
UV	ultraviolet
VL	visual lean
WBC	water-binding capacity
WHC	water-holding capacity
WME	warm-meat effect
WOF	warmed-over flavour

## **Part I**

### **Meat composition and additives**

## 2 Meat products handbook

# 1

## The protein and fat content of meat

Humans have eaten meat and meat products for thousands of years and our teeth have evolved so that they are shaped to tear apart and to chew meat. Countless highly valuable vitamins, minerals and trace elements are present in a concentrated form within meat, and meat and meat products remain part of a balanced and healthy diet today. There are also those, nevertheless, who opt not to eat meat for a variety of reasons.

Most countries today interpret pork meat in their respective food standards as meaning ‘muscle meat including fat and skin’, rather than lean muscle tissue only. This fact can be confusing to the ordinary consumer as most understand lean muscle tissue as ‘meat’ and do not know that fat and skin are classified as ‘meat’ as well. When other types of meat are described, however, the term meat does not include fat and skin. The amount of lean meat obtained out of a carcass is in cattle around 35%, in pigs around 45%, in veal around 38% and in lamb around 35%. Fat is also part of balanced human diet and the presence of fat in meat and meat products serves technological as well as organoleptic and nutritional purposes. The relationship between fat consumption and weight gain, however, is currently a topic of interest, as excessive consumption of fat may be a cause of the increased levels of obesity worldwide.

The quality of meat and meat products is also a topic of frequent discussion. There is currently no consensus on what the term ‘quality’ really stands for, given that ‘quality’ is generally seen as a combination of two major elements. On the one hand, ‘total quality’ of meat and meat products includes characteristics which can be measured, such as microbiological status, tenderness, colour, juiciness, shelf life, pH value and pesticide levels. On the other hand, total quality also includes an aspect which is less easy to measure: the consumer’s personal perception of the value of meat and meat products.

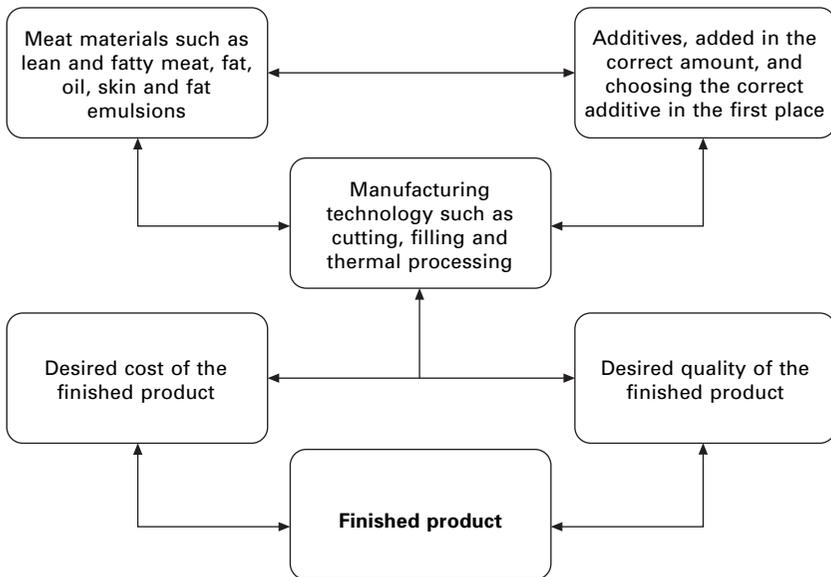
## 4 Meat products handbook

This perception is different for every individual human being as external factors such as television advertising for example have an influence on perceptions of total quality. The term ‘quality’, from the consumer’s point of view, could be simply said to mean whether the consumer thinks a product is good value for money and this judgement will vary from person to person and from product to product.

The study of meat technology (Fig. 1.1) is concerned with the three major building blocks used to make a meat product, namely raw materials, additives and the manufacturing technologies applied, as well as all possible interactions between the three. Manufacturing technology combines raw materials and additives with each other to obtain a product of the desired quality within a certain economic framework.

### 1.1 Amino acids

Amino acids are the building blocks of proteins. Even though around 190 amino acids are known today, only 20 different amino acids are required by humans to synthesize all necessary proteins. All these 20 amino acids are alpha-amino acids, given that both functional groups, the ‘acid’ carboxyl group ( $-\text{COOH}$ ), as well as the ‘alkaline’ amino group ( $-\text{NH}_2$ ), are attached to the same carbon atom, the  $\alpha$ -carbon atom or  $\text{C}_\alpha$ . This  $\alpha$ -carbon atom is also referred to as the ‘chiral centre’; glycine, the simplest amino acid, is the only non-chiral amino acid. The rest (R) of the molecule is in most cases the



**Fig. 1.1** Overview of meat technology.

primary portion of the amino acid and determines the identity of the amino acid itself as well as whether the amino acid is polar or non-polar.

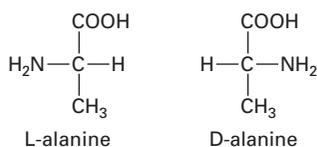
As stated above, almost all  $\alpha$ -amino acids are chiral, meaning that two arrangements of the same molecule are non-identical mirror images. Chiral amino acids exist in two configurations known as L or D stereoisomers (Fig. 1.2), which correspond to left-handed (L) or right-handed (D) three-dimensional shapes. D originates from the Latin word *dexter* and the  $\text{NH}_2$  group is on the right-hand side of the molecule, whilst L is from the Latin word *laevus*, meaning left. All amino acids found in proteins are L isomers except for glycine, the simplest amino acid, which is not chiral. Depending on the side chains within the amino acid, neutral, acid or alkaline amino acids are formed.

Amino acids exhibit side groups, which can be made out of a hydrogen atom or other ring-structured molecules (Fig. 1.3). In turn, those side groups can show different groups such as hydroxyl groups ( $-\text{OH}$ ) and, in conjunction with the carboxyl and amino group of the main structure of the amino acid, these affect the structure of a protein.

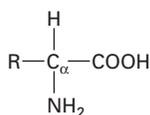
Eight of those 20 amino acids are 'essential' and have to be supplied to the human body by consuming food which contains these essential amino acids. The body cannot synthesize these eight essential amino acids. If they are not supplied to the human body via the intake of food, illness and even death may occur. The remaining 12 amino acids can be synthesized by the human body, as long as the food consumed provides all the elements needed to synthesize those amino acids. Protein-containing food is broken down by digestion into individual amino acids, from which the required body proteins are synthesized.

The essential amino acids are as follows.

Isoleucine	Threonine
Leucine	Valine
Lysine	Tryptophan
Methionine	Phenylalanine



**Fig. 1.2** L-alanine and D-alanine.



**Fig. 1.3** Typical configuration of an amino acid.

## 6 Meat products handbook

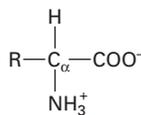
All the other 12 amino acids can be synthesized by the human body itself using nitrogen, which is supplied by consuming food containing nitrogen; these amino acids are the following.

Alanine	Asparagine
Arginine	Cysteine
Aspartic acid	Glutamic acid
Proline	Histidine
Tyrosine	Glutamine
Serine	Glycine

The nutritional value of food is determined by the presence of essential amino acids at their lowest relative concentration. A food might contain seven of the eight essential amino acids at a high concentration but one at only a very low level and it is the one present at a low level that determines the nutritional value of the food. This is based on the fact that, if only this particular type of food were consumed to provide essential amino acids, the one present at the low concentration would always be 'missing' and illness would be the result, given that the body cannot synthesize this one essential amino acid.

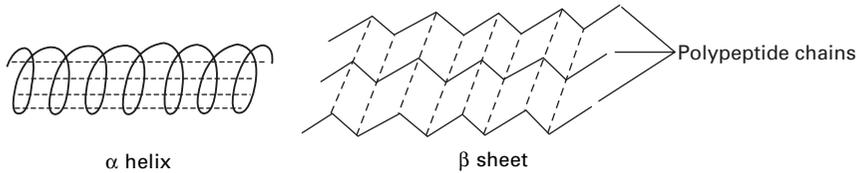
Amino acids are 'weak acids' present in a solution as zwitterions (Fig. 1.4) at a pH value of 5.4–5.7. In such a situation, the COOH group is present as a negatively charged COO<sup>-</sup> ion and can take up a hydrogen (H<sup>+</sup>) ion, while the NH<sub>2</sub> group is present as a positively charged NH<sub>3</sub><sup>+</sup> ion, which can give away, or donate, one H<sup>+</sup> ion.

Amino acids can act as an 'acid', or as an 'alkali', depending on their pH environment. At low pH values, or in a sour environment, the negatively charged carboxyl group (COO<sup>-</sup>) can take up an H<sup>+</sup> ion and act as an 'alkali'. The gain of a hydrogen ion neutralizes the COOH group and the entire amino acid becomes positively charged owing to the excess H<sup>+</sup> ion on the NH<sub>3</sub><sup>+</sup> group. In high-pH conditions, or in an alkaline environment, the positively charged NH<sub>3</sub><sup>+</sup> group of an amino acid releases an H<sup>+</sup> ion and acts therefore as an 'acid'. The NH<sub>2</sub> group is neutralized and the entire amino acid becomes negatively charged owing to the COO<sup>-</sup> group still present within the amino acids. Amino acids can donate or absorb H<sup>+</sup> ions without changing their pH value, which explains the 'buffer capacity' of amino acids and subsequently proteins. The buffer capacity depends on the concentration of ions donated or absorbed and, once the buffer capacity is exceeded, the pH value of the protein will change.



**Fig. 1.4** An amino acid present as a zwitterion.





**Fig. 1.6** An  $\alpha$  helix and  $\beta$  sheet structure of proteins.

by hydrogen bonds between amide groups of the peptide bonds, which are present along the chain of amino acids and other carbonyls. Hydrogen bonds show the characteristic H $\cdots$ H bridge. An  $\alpha$  helix is right handed and the  $\beta$ -pleated sheet structure is formed by the assembly of extended polypeptide chains lying side by side. The formation of either an  $\alpha$  helix or a  $\beta$ -pleated sheet depends on the sequence of amino acids in the primary structure. Overall, the secondary structure is a localized repetitious folding or twisting of the polypeptide chain in the primary structure.

- 3 *Tertiary structure.* Secondary structures unfold into three dimensions, giving rise to tertiary structures. Tertiary structures are supported by binding forces such as ionic bonds, hydrogen bonds, disulphide bridges, van der Waals forces and hydrophobic interactions. In tertiary structures, the folding is not predictable or repetitive as is the case within the secondary structure.
- 4 *Quaternary structure.* A quaternary structure is obtained when two or more individual polypeptide chains function as a single unit. The interactions between polypeptides create an oligomeric structure stabilized by non-covalent bonds. Loose hydrogen and sulphide bonds are present as well and the overall shape can be fibrous (threadlike) or globular. A well-known representative of a quaternary structure is haemoglobin, where the globin is surrounded by four haem molecules.

Complex structures such as the secondary, tertiary and quaternary structures are easily changeable. Changes in structure are known as denaturation, which can take place by the impact of temperature (cooking), pH values (acidification), high concentrations of salt (salting) or low levels of water-activity. As a consequence of denaturation, the protein changes its configuration from a highly organized and native structure into a less organized (denatured) and non-native structure. Because of this change in three-dimensional configuration, the protein loses its native form and is not 'functional' any longer. The process of denaturation is generally irreversible and the tertiary structure as well as the quaternary structure are primarily affected. Quite often, however, especially in irreversible denaturation, the secondary structure is affected as well, but the primary structure is not affected during the process of denaturation.

Analysing meat products with regard to their protein content takes place in most countries and is based on the Kjeldahl method. This method is based on 'finding' the total nitrogen within the meat product, given the fact that

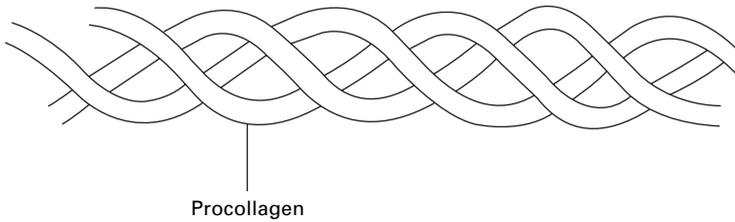
proteins contain a certain percentage of nitrogen (16%). Once the 'total' nitrogen is determined, the figure is multiplied by the factor 6.25, which results in the amount of protein present within meat or the meat product. The factor 6.25 originates from dividing 100 (total protein) by 16 (16% nitrogen) which gives, as stated, the factor 6.25.

### 1.3 Collagen

Collagen is a substantial part of connective tissue and is found in ligaments, tendons, skin and many other types of tissue serving mechanical and structural functions. Collagen accounts for almost one third of the total protein and is made from several different proteins. One of the major components is the amino acid hydroxyproline and this particular amino acid is present within collagen in a concentration of 12.5%. The amino acids proline and glycine are present at around 45–50% within collagen.

Collagen is stabilized against mechanical forces by cross-linking, which is induced by enzymes. Cross-links contribute to the enormous strength of collagen fibers and the enzyme responsible for the formation of those cross-links is lxyloxidase. Another form of stabilization within collagen comes from the presence of hydrogen- as well as other covalent bonds. The strength of collagen increases with increasing age of the animal and the solubility of collagen, in old animals, is reduced as a higher number of cross-links are formed within the collagen molecule at increased age. An analysis towards the content of collagen in a meat product is based in the first place on determining the amount of hydroxyproline present. The figure obtained for hydroxyproline is multiplied by a factor of 8, which is based on the above-mentioned fact, that collagen contains 12.5% hydroxyproline. Dividing 100 by 12.5, the factor 8 is obtained.

The building blocks for collagen are units of tropocollagen, which is a right-handed triple helix made out of three intertwined proteins, and numerous molecules of tropocollagen align themselves next to each other to form collagen. During this process, some amino acids are removed from individual tropocollagen molecules, which allows them to align next to each other to form collagen. Cross-links on the side chain of the amino acids lysine and histidine, as well as hydrogen bonds, stabilize those helices of tropocollagen within collagen. Such cross-links are unusual in proteins and only occur in collagen and elastin. A triple helix of tropocollagen is furthermore made out of three individual helices called procollagen. Each individual strand of procollagen exhibits a left-handed helix within itself. Thus, tropocollagen could be called a 'coiled coil', given that left-handed individual helices of procollagen form the right-handed triple helix of tropocollagen (Fig. 1.7) and such double coiling is ultimately responsible for the enormous strength of collagen. Every third amino acid within collagen is glycine, the smallest of all amino acids, and its presence helps to stabilize the triple helix. Collagen



**Fig. 1.7** A molecule of tropocollagen.

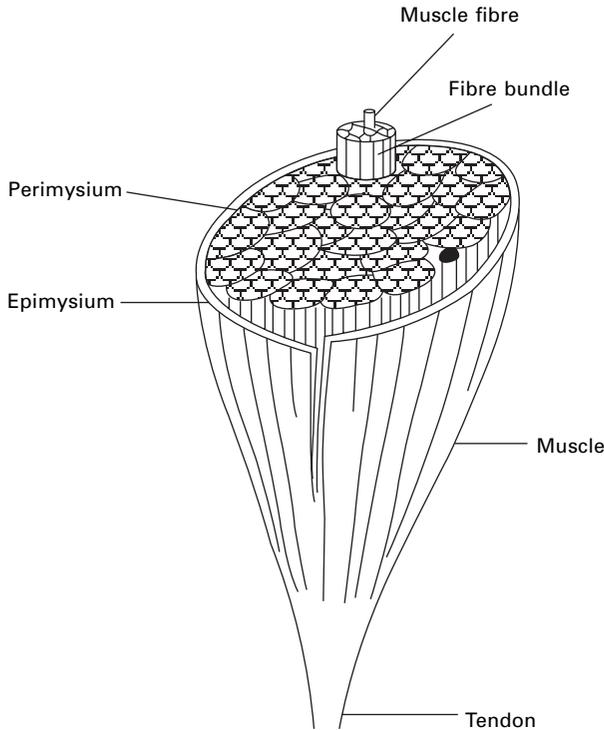
is insoluble in water and is also not soluble by the impact of salt and/or phosphates, whilst procollagen is water soluble. The triple helix swells if exposed to a sour medium for a prolonged period of time and ‘absorbs’, or holds, water during this process of swelling.

Collagen, when exposed to moist heat for a prolonged period of time, turns into gelatin, which forms a gel upon cooling. Prolonged periods of heat treatment turn gelatin again into individual strands of procollagen which, contrary to gelatin, does not form a gel upon cooling. The ‘solubility’ of collagen during heat treatment depends greatly on the number of cross-links present within triple helices (hydrogen- and covalent bonds), and increasing age of an animal leads to a higher number of cross-links, which in turn reduces solubility. As a result, hydrogen- as well as covalent bonds within collagen, which stabilize the molecule in the first place, reduce solubility at the same time. Collagen becomes ‘tender’ in raw dried products, such as prosciutto, by the impact of the enzyme collagenase, which is able to soften collagen over a prolonged period of time during ripening and drying of such products.

Elastin is another component present within connective tissue at around 4% of the amount of collagen and around 0.8% from the total meat protein. The amino acid hydroxyproline is found within elastin at 1% and elastin is yellowish in colour, almost insoluble in water and salt and is also resistant towards diluted acids.

## 1.4 Muscle physiology

A single muscle (Fig. 1.8) is covered by a thin layer of connective tissue called the epimysium, which is the extension of the tendon. Muscle is divided into muscle fibre bundles and another thin layer of connective tissue, called the perimysium, covers each fibre bundle. In turn, each fibre bundle is furthermore made out of individual muscle fibres, which are covered by a membrane of connective tissue known as the endomysium. Underneath the endomysium is another layer known as the sarcolemma, which is of net-like structure and is directly connected to the filaments actin and myosin, the major components of a muscle fibre. A liquid, called sarcoplasm (cytoplasm),



**Fig. 1.8** Structure of a muscle.

is the intracellular substance in a muscle fibre and consists of around 80% water as well as proteins, enzymes, lipids, carbohydrates, inorganic salts as well as metabolic by-products.

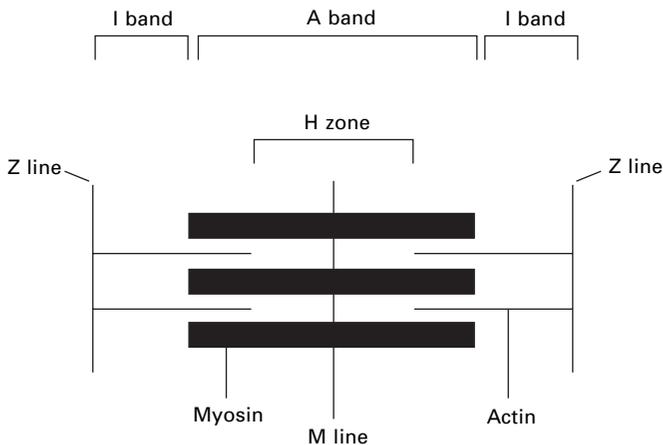
Lean muscle tissue contains between 70 and 75% water, 22% protein, around 2–4% intramuscular fat and around 2% of other components such as phosphates and minerals. The 22% protein can be divided into around 13% myofibrillar protein (salt soluble), 7% sarcoplasmic proteins (water soluble or soluble at very low salt concentrations) and around 2% structural proteins such as connective tissue (insoluble in salt and water). Expressed in percentages, the protein in lean muscle tissue consists of 55–60% myofibrillar protein, around 30% sarcoplasmic protein and around 10–15% connective tissue. The main myofibrillar proteins, adding up to 55–60% of the total myofibrillar protein, are myosin (around 42%) and actin (around 16%) as well as tropomyosin, troponin and actinin. Despite that, actin and myosin account only for around 7–8% of the total muscle weight, and only around 70 g per kilogram of meat is soluble protein coming from actin and myosin. Actin and myosin are also known as the myofilaments and are responsible for muscle contraction and relaxation.

Albumins and globulins are the main sarcoplasmic proteins and around 90 different proteins belong to the group of sarcoplasmic proteins. Albumins

are fully soluble in water whilst globulins are soluble in weak salt solutions only but insoluble in water. Myoglobin (colour of meat) and haemoglobin (colour of blood) are the most important types of globulin. Sarcoplasmic proteins are responsible for the metabolism in an animal cell. The main representative in the group of connective tissue is collagen (40–60%) and some tropocollagen, and elastin (around 10%) is present as well. Hence, a major part of connective tissue, around 30%, is made from other insoluble proteins. Myofibrillar proteins denature at around 67–72 °C whilst sarcoplasmic proteins denature generally at around 62–70 °C. Some sarcoplasmic proteins denature at temperatures as low as 50 °C. Connective tissue shrinks at 60–65 °C and continuous moist heat treatment up to around 90–95 °C turns collagen into gelatin. As stated earlier, prolonged heat treatment turns gelatin into individual strands of procollagen.

Water within muscle tissue is bound more or less firmly and in different ways. Protein-bound water within meat, around 4–6% of the water within the muscle tissue overall, is bound so firmly to protein that, even at a temperature of around –45 °C, protein-bound water is still not frozen. Around 55–60% of the water present between the myofibrils is bound in relation to the pH value of meat. Such fibril-bound water is known as immobilized (or not freely available) water but is not bound as firmly as protein-bound water. Water present in the sarcoplasm, around 20–25%, is freely available and is known as ‘free water’. Finally, extracellular water accounts for around 8–14% of the total water and is held outside cellular membranes in capillaries.

The contractile unit of a muscle fibre is a sarcomere (Fig. 1.9) and, for example, the human biceps exhibits around  $10^9$  sarcomeres. A sarcomere, which is around 2  $\mu\text{m}$  long, lies between two Z lines. Actin is connected to the Z line and comes to an end there. Myosin, on the other hand, is connected to the M line. The I band is the zone where no myosin overlaps with actin, and the H zone is the space where no actin overlaps with myosin. The A band

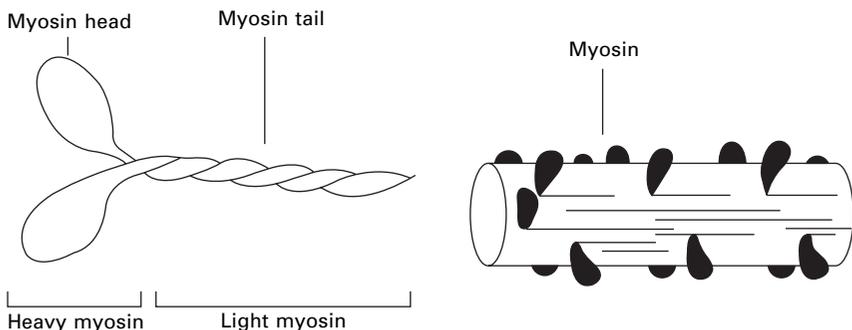


**Fig. 1.9** A sarcomere.

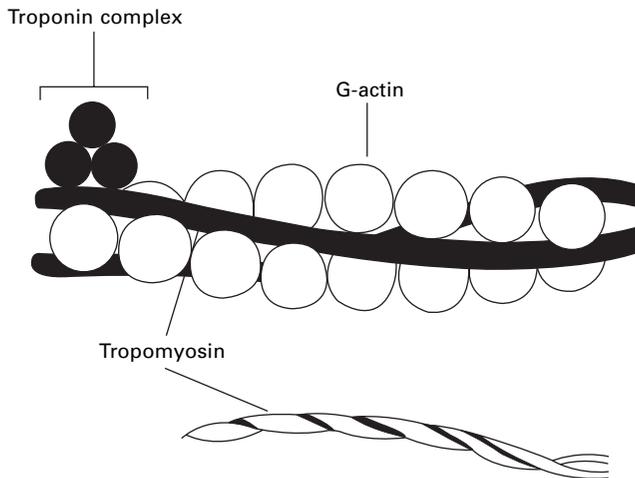
represents myosin. The special arrangement of actin and myosin give the fibre a striated appearance under the microscope, and actin and myosin are arranged in a structured hexagonal pattern.

Myosin, the 'thick' filament, is made from around 280 molecules of individual units of the protein myosin, which exhibits a long tail as well as two pear-shaped heads (Fig. 1.10). The molecular weight of myosin is around 490 000 Da and the tail of the molecule is called light myosin, whilst the head is known as the heavy myosin. The isoelectric point (IEP) of myosin, where negative and positive charges are of the same number within the protein, is at a pH value of 5.0. Myosin is soluble in salt concentrations ranging from 1 to 6%. For a salt concentration above 6%, myosin is denatured owing to the high level of salt and is not native (functional) any longer. The tail of the myosin molecule is rich in acid as well as alkaline amino acids and the  $\text{COO}^-$  as well as the  $\text{NH}_3^+$  groups are attracted to each other inside the tail. Those charged ions hold the thick filament together and are also responsible for the limited solubility of myosin in water. Myosin also carries the enzyme myosin ATP-ase (where ATP is adenosine triphosphate), which plays a major role in the movement of muscle fibres during the contraction and relaxation of a muscle.

Actin, the 'thin' filament, consists of monomeric or globular G-actin, which form the filamentous, or fibrillar, F-actin as well as troponin, tropomyosin and actinin (Fig. 1.11). The molecular weight of G-actin is around 40 000 Da and it is made out of around 350 amino acids. Around 360 molecules of G-actin are required to polymerize and to form F-actin, which are two strings of actin globules wound around each other in a double helix like a pearl chain. Such a pearl chain of F-actin is curled around the string-like tropomyosin, which is made out of two curled strings on its own. After every seventh actin molecule, a troponin complex made out of troponin I, C and T is attached to actin and such troponin exhibits a high affinity towards  $\text{Ca}^{2+}$  ions. Troponin and tropomyosin have a controlling or regulating impact on the contraction and relaxation of the muscle fibres but are not directly involved in the contraction and relaxation as such. Denaturation of those contractile fibres myosin and actin starts at 55–60 °C.



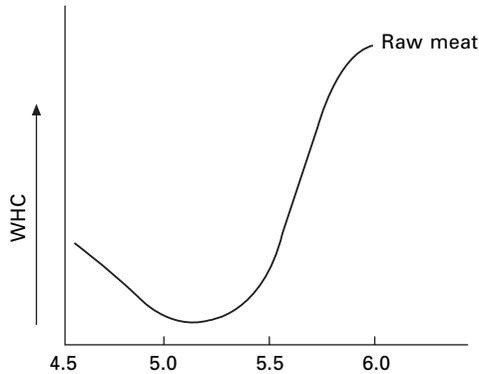
**Fig. 1.10** Single unit of myosin and thick filament.



**Fig. 1.11** Actin and its subunits.

The amount of water bound within muscle tissue depends to a large degree on the space available between the fibres actin and myosin and the pH value plays a vital role. Generally, pH values above and below the IEP result in enhanced water-holding capacity (WHC) but within muscle tissue the levels above the IEP are of importance (Fig. 1.12). A decline in pH value toward the IEP in meat results in less WHC. At the IEP of the actomyosin complex, with a pH value of 5.2, most  $\text{COOH}$  groups are present as  $\text{COO}^-$  anions and most  $\text{NH}_2$  groups are present as  $\text{NH}_3^+$  cations. Those positive and negative ions attract each other and the protein molecule is tightly bound together. At this point, the protein molecule shows a net charge of zero as there are the same numbers of positive and negative charges present within the protein molecule. As a result, only a tiny amount of water can be bound within the proteins. An increase in the number of charges, positive or negative, within the protein molecule increases the WHC, because the protein is not as tightly bound together as is the case at the IEP. When negative charges outnumber the positive charges, the pH value of the protein is above the IEP and such a condition results in increased WHC. The fibres (filaments) are repulsed and the space or gap between actin and myosin is enlarged, which allows more water to be incorporated. Within fresh meat, a very similar effect can be seen at a pH value below the IEP when positive charges outnumber the negative charges.

If  $\text{NH}_3^+$  groups are present in muscle tissue as neutral  $\text{NH}_2$  groups and the binding forces between actin and myosin are weaker. When the binding forces are weaker, enhanced levels of water can be immobilized within the fibre structure and such immobilized water is not freely available but quite firmly bound. Hence, there is increased repulsion between actin and myosin, and the capillary effect is enhanced as well, which supports uptake of water once again. The capillary effect can be compared with a slight 'sucking'



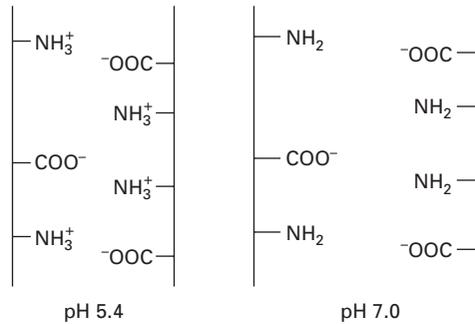
**Fig. 1.12** Effect of pH on the water-holding capacity (WHC).

effect and is seen if a straw is placed in a glass of water as the level of water within the straw is above the level of water in the glass. The positive impact of the capillary effect on the WHC of muscle tissue ends at a pH value around 6.4, as the individual fibres are so far apart from each other at this point, that the 'sucking' effect no longer takes place. In summary, an elevated pH value (increase in negative charges) in muscle tissue creates larger gaps between actin and myosin owing to increased repulsion forces (Fig. 1.13), combined with the capillary effect, and more water can be immobilized.

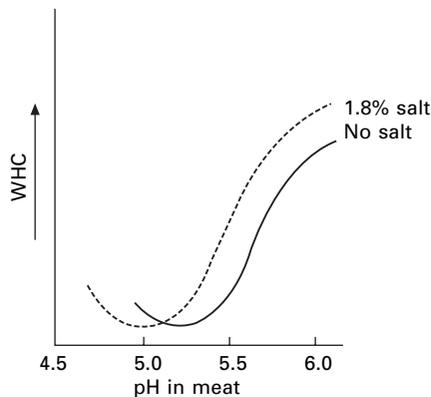
The introduction of salt into muscle tissue changes the number of charges on the muscle fibres, which in turn causes swelling of the fibre structure, and the WHC is enhanced as a consequence (Fig. 1.14). Positively charged sodium ions ( $\text{Na}^+$ ) are bound fairly weakly by negative charges within the protein molecule. On the other hand, the negative chloride ion ( $\text{Cl}^-$ ) is bound strongly within the molecule and becomes neutralized or is basically taken out of the equation. The 'light' binding of the sodium ion causes a slight movement of the IEP within the muscle meat towards a lower pH value, around 5.0, and at the same time creates a larger space between the fibres at a certain pH value present in meat.

## 1.5 Flavour of meat

Generally, raw meat itself does not demonstrate a great deal of flavour, and the flavour intensity increases with increasing age of an animal regardless of the type of animal. For example, beef from an animal that is only 1 year old, does not exhibit as much beef flavour as beef originating from a 2 year old animal. The same principle of age regarding flavour applies to pigs and poultry. Generally, meat from an older animal of the same species exhibits stronger flavour than meat from a young animal.



**Fig. 1.13** Impact of pH on the repulsion forces between actin and myosin.



**Fig. 1.14** Increased water-holding capacity (WHC) due to the addition of salt.

Meat contains around 1.3 g of sodium chloride per kilogram as well as 3 g of potassium and both contribute to the slightly 'salty' and 'bitter' taste of raw meat. There is little sugar in meat except in meat originating from horse (around 1%) or deer such as venison. The 'sour' component of meat is primarily based on lactic acid obtained during post-mortem glycolysis. Another contribution to flavour comes from the degradation of adenosine diphosphate (ADP) finally into inosine monophosphate, which is ultimately converted into inosine and hypoxanthine. Both substances add some degree of 'bitter' flavour to meat. This aspect of added bitterness is present in a stronger form within dark firm dry (DFD) meat. Given that less lactic acid is produced in DFD beef meat (see Chapter 4, Section 4.1) during rigor mortis, the overall flavour is not as strong as in 'normal' beef meat. Hence, inosine monophosphate, originating from ADP during post-mortem glycolysis and present in meat, is converted in DFD meat to a larger extent into hypoxanthine, a slightly bitter-tasting substance. The flavour of raw meat is also influenced to some degree from sulphuric components present in meat. Other flavour components in meat are amino acids, peptides and carbonic acids. During ageing (ripening and maturing) of meat, lipolysis (breakdown of fats) as well as proteolysis

(breakdown of proteins) causes proteins and fat to become a much more significant part of meat flavour. Pork meat also contains several different lactones, which contribute to the typical pork flavour.

Once meat is cooked, the flavour intensifies with substances such as alcohols, aldehydes, ketones and lactones generating flavours. Pork fat produces upon heating two saturated aldehydes as well as two unsaturated aldehydes, which are not present in heated beef, chicken or lamb fat. Heat treatment by the impact of high temperatures such as grilling creates ring-shaped molecules, responsible for the typical grill flavour contrary to the saturated ketones, aldehydes and acids produced during low-temperature heat treatment obtained by processes such as steam cooking and simmering. Through the impact of heat, the Maillard reaction (see Chapter 4, Section 4.13) takes place in meat and the presence of the sulphur-containing amino acids cysteine and methionine leads to very flavoursome components. Hence, carbonyl components such as oxopropanol and methylfurfural, obtained from the Maillard reaction, contribute greatly to the flavour of cooked meat as well.

Boneless cuts of meat are commonly packed under vacuum for easier and prolonged storage as well as hygienic handling. Once removed from the packaging, such meat has to be exposed for around 10 min to fresh air to regain its original flavour. Within vacuum packaging, an atypical flavour is created as a result of the vacuum applied.

Pale soft exudative (PSE) and DFD meat (see Chapter 4, Section 4.1) exhibits a reduced amount of glycogen and, by preparing food with such meat, the Maillard reaction takes place in a weaker form, creating less flavour as a result. Boar meat contains the sex hormones androstenone and testosterone as well as scatol, which create a 'flavour' widely disliked by people, especially by females. Chicken meat receives its flavour primarily from unsaturated aldehydes, which originate from linoleic acid. Occasionally, a slight 'fishy' flavour can be observed in chicken and turkey, and the cause for that seems to be feed containing high levels of unsaturated fats.

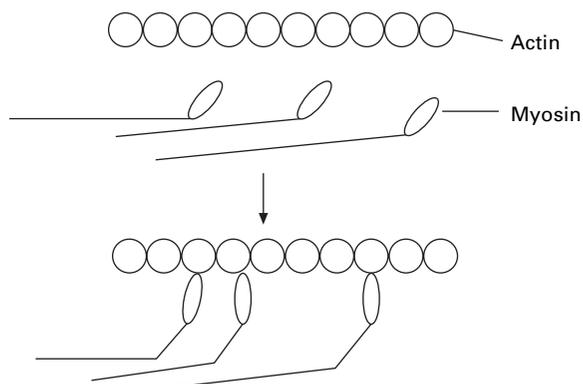
Warmed-over flavour (WOF) is predominantly seen in reheated uncured cooked meats and when a form of rancidity occurs at a very fast speed. In cured meats, containing nitrite at levels of around 40–50 ppm/kg, the WOF is greatly reduced. As stated, the WOF is the result of an oxidation, where iron ions that are released during reheating of already cooked uncured food speed up oxidation on unsaturated fatty acids, which are predominantly seen in intramuscular fat. The degree of WOF depends on the level of iron ions present within food as well as on the level of unsaturated fatty acids. Other factors, such as the storage temperature and the period that the cooked meat was stored, also play a role in the intensity of the WOF. Prolonged storage generally enhances WOF afterwards during reheating. The intensity of WOF follows the sequence lamb < beef < pork < poultry, with poultry showing the strongest WOF in reheated foods, which is primarily based on the fact that poultry fat contains the highest amount (around 40%) of unsaturated fatty acids. Antioxidants such as butylated hydroxytoluene (BHT), tocopherol

and rosemary (see Chapter 6, Section 6.10) are applied in order to control WOF. Occasionally, enhanced levels of spices are applied to overcome, or to cover up, the WOF. A metal chelating agent such as the salts of ethylenediaminetetraacetic acid and citrates are also used in order to slow down oxidation. A combination of applying an antioxidant and packing food under vacuum is very effective to reduce the level of WOF.

## 1.6 Principles of muscle contraction and relaxation

In a relaxed muscle, the level of  $\text{Ca}^{2+}$  ions is very low and the troponin present does not allow the myosin head to bind to the actin. As a result, the muscle stays relaxed. The contraction of a muscle is heavily regulated by  $\text{Ca}^{2+}$  ions, released from the sarcoplasmic reticulum (SPR), based on a nervous impulse. As a result of this nervous impulse, the concentration of  $\text{Ca}^{2+}$  ions increases in the sarcoplasm from  $10^{-7}$  to  $10^{-6}$  mol/l which leads to a rearrangement of the troponin and tropomyosin to face myosin. The SPR is a complex membranous network covering each myofibril and its main function is to maintain a balance between  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions, controlling enzyme activity as well as controlling the levels of ATP, creatine phosphate (CP) and glycogen within the muscle. Excess ATP is stored in the muscle in the form of CP and ADP and muscle contraction, as well as relaxation, is an energy-consuming process.

In cases of urgent need (heavy muscular work), energy in the form of ATP is provided by the reaction  $\text{CP} + \text{ADP} \rightarrow \text{creatine} + \text{ATP}$ . The release of  $\text{Ca}^{2+}$  ions triggers the activation of the enzyme myosin-ATP-ase and causes ATP to hydrolyse into ADP, phosphate and free energy following the reaction  $\text{ATP} \rightarrow \text{ADP} + \text{P}_i + \text{energy}$ . The energy obtained leads to a change in the configuration of the myosin head, making it bind with actin (Fig. 1.15), and

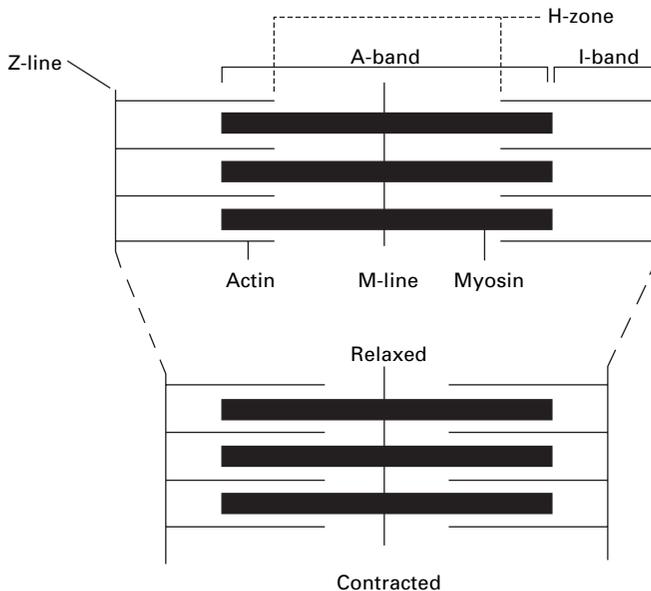


**Fig. 1.15** Binding of myosin and actin by changing the configuration of the myosin head.

a contracted muscle is obtained. As a result, actin and myosin are no longer present as separate fibres but as the actomyosin complex. Within such a complex, actin and myosin are tightly bound together via cross-links.

As stated above, actin undergoes a slight change in configuration in order that the myosin head can actually bind to the actin upon a nervous impulse by calcium ions binding to actin. Actin slides towards, or into, myosin and therefore the degree of overlapping between actin and myosin is enhanced in comparison with the degree of overlap if the muscle is relaxed. This 'sliding theory' is based on the fact that the widths of the I band and H zone decrease during contraction as the thin filaments are drawn into the space between the thick filaments in the centre of each sarcomere. Even by doing so, the width, or thickness, of the actin and myosin filament itself does not change during this sliding process. It is just that the thin filament (actin) slides deeper into the H zone (see Fig. 1.9) and a greater degree of overlapping takes place. Because of this greater overlapping, the length of a sarcomere is shortened and the shortening of thousands of such individual sarcomeres causes the muscle to shorten overall. The length of an individual sarcomere can be reduced by up to 50% during contraction.

Relaxation of a muscle after contraction occurs via the removal of  $\text{Ca}^{2+}$  ions and the SPR absorbs the excess  $\text{Ca}^{2+}$  ions again from the sarcoplasm (Fig. 1.16). The enzyme actin–myosin ATP-ase is activated in order to obtain ATP required for the separation of actin and myosin to turn the actomyosin complex into a relaxed muscle again, where both filaments are present in their separate states. The energy required for both muscle contraction and relaxation comes from the hydrolysis of ATP and, during such muscle fibre



**Fig. 1.16** Relaxed and contracted sarcomeres.

movement, chemical energy coming from ATP is converted into mechanical energy.

## 1.7 Enzymes in meat

Enzymes are proteins and their names usually have an -ase ending. They are generally large globular proteins and the main characteristic of enzymes is that they can trigger, or speed up, chemical reactions within meat without being consumed during the process of the action. Enzymes act as biocatalysts by increasing the rate, or speed, of a reaction by a factor of  $10^3$ – $10^{10}$ . Each enzyme acts very specifically such as splitting certain molecules only or speeding up certain chemical reactions. Also, each enzyme is characterized by specificity for a very narrow range of chemically similar substrates or reactants. The specific arrangement of an enzyme's amino acid side chain in the active site determines which type of molecule is able to react with a certain enzyme. Each enzyme has a specific three-dimensional shape with a specific surface configuration, which makes their action, or the place of action, very specific once more.

Enzyme activity is greatly influenced by pH value and temperature. Most enzymes present in meat are 'working at their best' between 25 and 50 °C and activity is greatly reduced at lower pH values. The most common enzymes in meat are as follows.

- 1 *Lipases*. Lipases are lipid-hydrolysing enzymes placed in the lysosomes of a cell and are secreted by microorganisms. The enzyme breaks down fat into glycerol and free fatty acids in a process called lipolysis. Lipolysed fat smells and tastes rancid and this particular smell and taste originate from low-molecular-weight fatty acids such as butyric and caproic acid. However, a certain degree of lipolysis is desired in products dried for a long time such as salami and air-dried hams in order to obtain the product-typical slightly rancid taste. A high number of free fatty acids speed up rancidity in meat products. Lipase, to a great extent, is deactivated at 72 °C but a temperature of 80–82 °C is necessary to deactivate this enzyme totally.
- 2 *Proteases*. Several different types of protease are present in meat and those enzymes break down proteins into peptides as well as free amino acids in a process known as proteolysis (the ending 'lysis' refers most commonly to breakdown of substances). Proteases act in many different ways within meat and meat products and their function as a 'tenderizer' is one of the most important (see Chapter 3, Section 3.1). Hence, the proteolysis taking place in products such as salami and air-dried hams has a major contribution to the typical, and desirable, slightly 'rotten' flavour of such products, which is mainly based on sulphur-containing metabolic by-products of enzyme activity.

- 3 *Collagenases*. Collagenases are able to soften collagen and specifically to break down bonds within the triple helices that form collagen and, by doing so, a higher number of individual molecules of tropocollagen are obtained (see Section 1.3). Hence, the bonds present within a molecule of tropocollagen are loosened as well. The bacteria *Pseudomonas aeruginosa* produces the enzyme collagenase (which is a protease) and it hydrolyses the collagen in the connective tissue.
- 4 *Catalase*. Catalase splits hydrogen peroxide ( $H_2O_2$ ) into water and oxygen at an enormous speed. Around 400 000 molecules of  $H_2O_2$  can be split within 1 s. One unit of catalase is defined as the amount of extract needed to decompose 1  $\mu$ mol of  $H_2O_2$  per minute.  $H_2O_2$  is a very 'aggressive' and slightly viscous substance, which leads to discolouration in meat products on the one hand and also speeds up rancidity in raw fermented salamis on the other hand. Based on that, starter cultures commonly applied in the production of raw fermented salami contain catalase-positive microorganisms. The enzyme catalase is deactivated by exposure of the enzyme to a temperature of 74 °C for 60 s.
- 5 *Phosphatase*. Phosphatase can split phosphoric acid esters into phosphoric acid and the corresponding alcohol. The degradation of phosphates within meat itself and added phosphates to meat products is partly a result of the activity of the enzyme phosphatase. This enzyme is destroyed by exposing it to a temperature of 72 °C for 25 s.
- 6 *Glycosidase*. Glycosidase is able to split glycosidic bonds between carbohydrates.

## 1.8 Fat

Fats, or lipids, are the most concentrated source of food energy and are necessary to health. Carcass fat contains around 80–85% triacylglycerol fat, 5–10% moisture and around 10% connective tissue. For the context of this book, fat is seen as fatty tissue, because fatty tissue and fat are by definition not the same as fat which refers to the fat material only without water or connective tissue. Fat is a non-polar molecule and unlike water, which is polar, fat does not exhibit a negative and positive end (pole). Fat, or lipids, are therefore insoluble in water because of the presence of insoluble carbon–hydrogen components within the molecule. Food fats are carriers of fat-soluble vitamins and some essential unsaturated fatty acids.

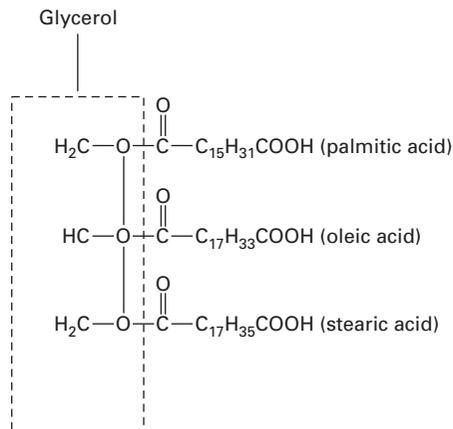
Fat is generally colourless but exhibits occasionally a touch of yellow and is by nature extremely hydrophobic (lipophilic). Fat from cattle fed with fresh grass containing carotene frequently shows a yellow tinge, and fat itself carries some flavour but is an excellent solvent for countless other flavour and aroma components. Depending on the types of fatty acid present in meat, the flavour can vary dramatically. Pork fat produces upon the impact of heat saturated as well as unsaturated aldehydes, which are typical of pork

flavour. Such components are hardly present in beef fat as beef fat contains predominantly saturated fatty acids. Some branched fatty acids are found within fat originating from sheep, which are responsible for the pronounced sheep, or lamb, flavour. The difference in flavour and taste of different types of fat is not solely based on pure fat but is more due to the heat treatment of fatty tissue overall. Fatty tissue, as well as fat, also contains connective tissue as well as other amino acids, which contribute to a large extent to the various flavours originating from different types of fat. Fatty acids, such as oleic acid, show a positive impact towards the flavour of fat whilst stearic acid and linolenic acid demonstrate a negative impact on the flavour of fat overall.

Fats are divided into three major groups.

- 1 *Intramuscular fat* (fat between the muscle fibres and fibre bundles). It is also known as the marbling fat and as such plays a major role towards juiciness, flavour and tenderness of meat. The world-famous Kobe beef in Japan shows extremely high levels of such marbling fat which, as well as other factors such as a very special diet and treatment of the animal overall, contributes to the very tender, juicy and tasty meat.
- 2 *Intermuscular fat* (between individual muscles).
- 3 *Subcutaneous or depot fat* (under the skin).

The building blocks for fat (or simple lipids) are triglycerides and fat is made out of molecules of carbon, hydrogen and oxygen. Other substances, known as complex lipids, also contain phosphorus, nitrogen and sulphur besides carbon, hydrogen and oxygen. Triglycerides in fat are esters of the trihydric alcohol glycerol and three fatty acids (three of the same type or three different types) are bound to glycerol (Fig. 1.17). An ester is a compound formed by the reaction between an alcohol and acid with the removal of water. The reaction is the following: alcohol (glycerol) + acid (fatty acids) → ester + water.



**Fig. 1.17** Triglyceride showing glycerol and three fatty acids.



This fact gives rise to either a *cis* or a *trans* configuration of fatty acids and the Latin prefixes *cis* and *trans* demonstrate the location of the hydrogen atoms in respect of the double bond. *Trans* means on the other or opposite side, whilst *cis* means on the same side. Fatty acids generally exhibit the *cis* configuration whilst the *trans* configuration is more often present in nature overall (Fig. 1.19).

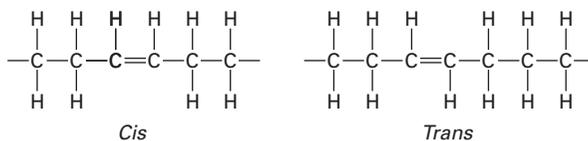
Fatty acids demonstrating both the same number of carbon atoms and the same number of double bonds at the same carbon number become different fatty acids depending on whether the *cis* or *trans* configuration is present.

The different types of fats are as follows.

- 1 Saturated fats.
- 2 *Trans* fats (behave similarly to saturated fats).
- 3 Monounsaturated fats.
- 4 Polyunsaturated fats.

The saturation of fat refers to the chemical structure of its fatty acids. Saturated fatty acids are of linear structure (non-branched) and generally exhibit even numbers of carbon atoms within their molecule such as 16 or 18 carbon atoms. Single-bond linkages are present in saturated fatty acids between carbon atoms and no double bond is given. Such single-bond linkages are chemically not very active and saturated fatty acids are commonly solid at room temperature. Animal fats are predominantly saturated fats or contain a high amount of saturated fatty acids. Important representatives of saturated fatty acids present in animal fat are stearic acid (C18:0) as well as palmitic acid (C16:0). The 0 shows that no double bond is present within the fatty acid, which is made from 18 (16) atoms of carbon. Beef fat contains a high level of saturated long-chained fatty acids. The degree of saturation in fat decreases in the sequence beef > pork > poultry > fish (least saturated). Stearic acid is unique in as much as it does not raise blood cholesterol and unfortunately is very often associated with other saturated fatty acids, which do raise blood cholesterol. Major sources of stearic acid are chocolate, lard, tallow and commercial fats and butter. Palm oil and coconut oil are also rich in saturated fatty acids.

Unsaturated fatty acids contain one or more double bond(s) between carbon linkages and the double bonds in unsaturated fatty acids regularly show a *cis* configuration. Monounsaturated fat is a type of fat in which the fatty acid contains one double bond in its chemical structure. Such fatty acids are found in olive oil, canola oil and peanut oil as well as avocados. Oleic acid



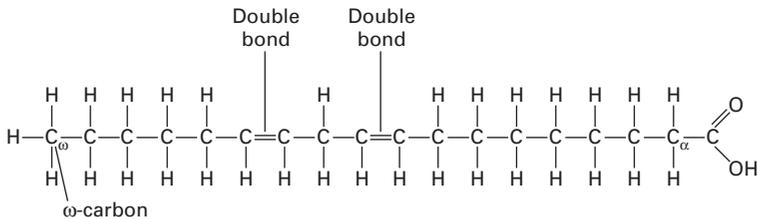
**Fig. 1.19** *Cis*- and *trans*- configurations in fatty acids.



$\omega 3$  and  $\omega 6$  fatty acids are essential unsaturated fatty acids and have to be provided to the human body by eating foods containing those fatty acids, given the fact that the human body cannot build them from other fatty acids. Polyunsaturated fatty acids are named by counting from the methyl ( $-\text{CH}_3$ ) end within the fatty acid. Letters from the Greek alphabet such as  $\alpha$ ,  $\beta$ ,  $\gamma$  to  $\omega$  are utilized in order to determine the location of double bonds within the polyunsaturated fatty acid.  $\omega$  is the last carbon atom in the chain of carbon atoms counted from the carboxyl ( $-\text{COOH}$ ) end as the letter  $\omega$  is the last letter in the Greek alphabet. For example, linoleic acid is an  $\omega 6$  fatty acid and the first double bond, counted from the methyl end, is located six carbon atoms away from the  $\omega$ -carbon atom. This  $\omega$ -carbon atom is the same carbon atom as used within the methyl group ( $\text{CH}_3$ ) and carbon atom number 18 from the carboxyl end. Polyunsaturated fats, such as corn oil, are generally liquid at room temperature as well as under refrigeration.

Different types of fat exhibit different melting points and as a result have a different impact on the mouth feel in meat products. Fats containing a high number of saturated fatty acids (such as kidney fat or lard) cause a greasy, smeary and sandy mouth feel whilst more unsaturated fats give a pleasant taste as well as a smooth non-sandy mouth feel. Generally, the 'hardest' fat within a carcass showing high levels of saturated fatty acids is found in the centre of the carcass and softer fats are placed towards the outside of a carcass. Even in subcutaneous pork fat, such as pork back fat, the outer layer of pork back fat, which is directly connected with the skin, is softer than the inner layer. Hence, soft fat contains a higher amount of connective tissue within itself compared with hard fat, and chicken fat, which is the softest fat (a high amount of unsaturated fatty acids), contains the highest level of connective tissue. On the other hand, beef fat, which is of hard consistency, exhibits the lowest level of connective tissue. Pork fat lies between chicken and beef fat in terms of the level of connective tissue within the fat itself. In summary, soft fat contains higher levels of connective tissue but fat molecules entrapped within connective tissue are of soft consistency (a high degree of unsaturated fatty acids). Hard fat, on the other hand, contains less connective tissue but fat molecules covered by connective tissue are of hard consistency (a high degree of saturated fatty acids).

The melting point of a fatty acid depends largely on the length of the fatty acid itself as well as the number of double bonds present. Saturated fatty



**Fig. 1.22** Linolenic acid.

acids generally show a higher melting point than unsaturated fatty acids do. The double bonds (and therefore less hydrogen within a fatty acid) present in unsaturated fatty acids, lower the melting point, and unsaturated fatty acids show generally a lower melting point than saturated fatty acids as a result. An increased number of double bonds within a fatty acid lowers the melting point once again. An increased length of a fatty acid containing a higher number of carbon atoms causes an increase in melting point. For example, stearic acid (18 carbon atoms) has a melting point of around 70 °C whilst capric acid (ten carbon atoms) shows a melting point of around 30 °C. Overall, the melting point of beef fat is around 43–47 °C, pork fat around 38–44 °C and chicken fat around 31–37 °C. Hence, fat containing *cis*-shaped double bonds within the fat molecule exhibits a lower melting point than fat containing *trans* double bonds.

The consistency of fat largely depends on the saturation of the fatty acids. A higher number of unsaturated fatty acids leads to ‘softer’ fat. Pork fat contains a relatively high amount of unsaturated fatty acids and is ‘soft’ as a result. Beef fat, on the other hand, contains predominantly saturated fatty acids and is therefore of a ‘hard’ consistency. The level of saturated fatty acids within fats varies and is for beef around 55–60%, for pork around 42–44% and for chicken only 30%. This explains the ‘hardness’ of fat in the sequence beef ≥ pork ≥ chicken, with chicken being the softest. Lamb and mutton are similar to beef with regard to the content of saturated fatty acids. For the production of meat products, pork fat, which has a small number of unsaturated fatty acids such as fat from loin and neck, is the preferred choice over soft pork fat, from the leg and shoulder, showing a higher number of unsaturated fatty acids. Such ‘soft’ fat is best utilized for emulsified sausages and is not recommended for products such as salami, where ‘hard’ fat is needed as it can be cleanly cut and the tendency towards rancidity is reduced as well.

Vegetable fats are predominantly liquid because of their high level of unsaturated fatty acids. During hardening of fat, double bonds are destroyed and a reduced number of double bonds increases the melting point. Such treatment helps to regulate the melting point in products such as margarine.

## 1.9 Rancidity of fat

Unsaturated fatty acids showing double bonds within the molecule are susceptible to peroxidation. Such peroxidation could be called ‘oxidative deterioration’ of lipids and can occur via a radical reaction in two ways. One way, and by far the most important, is autoxidation. The other way, which is less important, is enzymatic oxidation. Oxidation is a process where an oxygen ion replaces a hydrogen ion within a fatty acid molecule and where higher numbers of double bonds within the fatty acid increase the possibility

of autoxidation. Pork and chicken fat demonstrate a higher degree of unsaturated fatty acids than beef fat does and are therefore more prone to rancidity.

The availability or presence of oxygen, increased temperatures, the impact of light and the presence of pro-oxidants speed up autoxidation (oxidative rancidity) over a period of time. Autoxidation does not take place from one day to another but the potential for the chain reaction to start increases over time and, once triggered, takes place at a fast rate. The presence of pro-oxidants such as iron and copper ions accelerates the onset of autoxidation as does the presence of oxygen and exposure to light, especially direct sunlight or light from fluorescent tubes. Iron and copper ions can be deactivated by the addition of chelating agents such as citric acid. The oxidation of fat occurs at a faster rate at a reduced water content, because water acts as a 'barrier' against the reaction of fatty acids with oxygen. The smaller the quantity of water within food, the more 'effective' the oxygen is towards oxidation.

Autoxidation is an oxygen-induced radical-chain reaction and can be divided into the three phases of initiation, propagation and termination. During the initiation phase, free radicals are obtained. Those free radicals react with other materials during the propagation phase and non-radical products are obtained during the phase of termination. It was thought in the past that oxidation occurs directly on the double linkages between two carbon atoms within fatty acids but it is known today that a double linkage between two carbon atoms favours the oxidation of the neighbouring carbon linkage. The placement of oxygen on a carbon linkage within an unsaturated fatty acid is known as peroxidation. The removal of hydrogen from the fatty acid, through the impact of oxygen, causes the formation of a fatty-acid radical as well as a hydrogen radical. Through such a process, an oxygen ion replaces a hydrogen ion within a fatty acid (initiation phase).

A radical is a molecule, or part of a molecule, with a non-saturated pair of electrons and therefore a highly reactive substance. Radicals are rich in energy and are generally obtained when a non-radical loses one electron; a radical is symbolized in a chemical formula with a dot such as  $[R^{\cdot}]$  or as  $[R^*]$ . As stated, radicals are extremely reactive because of the lack of an electron and, being in such an 'unstable' state, the radical tries to stabilize itself by obtaining an electron from another molecule to restore its stereochemical stability. The fatty-acid radical reacts with other fatty acids and results in the formation of new radicals and the removal of an electron from another non-radical material to stabilize the original radical that caused the formation of another radical. As a result, a self-feeding chain reaction is started. Upon the availability of oxygen, radicals bind with oxygen and activated peroxide radicals are the result. Such peroxide radicals are stabilized via the binding of hydrogen atoms, originating from other fatty acids, and hydroperoxides are the result. All those reactions of radicals with other substances take place during the propagation phase.

A hydroperoxide is by itself a non-radical intermediate but creates within the ongoing process of autoxidation one radical and one peroxide radical.

Hydroperoxides are also neutral from a sensorial point of view but demonstrate an extremely high potential for oxidation. They ultimately fall apart in the termination phase into countless relatively unreactive components including aldehydes, hydrocarbons and ketones but also, as stated before, new radicals (highly reactive). Some of the aldehydes obtained from hydroperoxides are malondialdehyde and its isomeric combinations hydroxyacrolein and ephedrine aldehyde. Aldehydes and ketones, originating from hydroperoxides, are primarily responsible for the rancid smell of fat. Both of those substances are well suited to testing fat regarding its state of rancidity. The self-feeding chain reaction as well as the fact that hydroperoxides create new radicals explains that oxidation cannot be totally stopped once it started; it can only be delayed. Up to 100 peroxides, or hydroperoxides, can be formed from one radical, which explains why, once autoxidation has started, it continues in an exponential way within the propagation phase.

Hydrolytic rancidity based on enzymatic oxidation is another radical-based reaction but of much less significance than oxidative rancidity. During this process, lipases create free fatty acids, which are afterwards prone to oxidation. Such hydrolytic rancidity can also be started by the reaction between water and lipids. The application of antioxidants, or storage of fatty meat (or fat) at  $-18\text{ }^{\circ}\text{C}$ , does not stop the process of fat turning rancid. Some lipases exhibit activity even at temperatures as low as  $-28\text{ }^{\circ}\text{C}$ .

Photo-oxidation is another form of oxidation and oxygen changes its configuration from triplet oxygen ( $^3\text{O}_2$ ) to singlet oxygen ( $3 \times ^1\text{O}_2$ ) during the process through the impact of short-wave ultraviolet (UV) light. Singlet oxygen ( $^1\text{O}_2$ ) is significantly more reactive than triplet oxygen and reacts with unsaturated fatty acids to form hydroperoxides, which in turn break down to free radicals; thus the above-mentioned chain reaction starts again. Within autoxidation, the oxygen involved never changes its configuration, which is a distinctive difference from photo-oxidation, where the oxygen involved changes to singlet oxygen.

The presence of light also demonstrates a large impact towards obtaining and speeding up the process of rancidity. It is well known that fatty meat (or fat) stored in darkness at freezing temperatures develops rancidity at a much slower rate than the same materials would when stored at the same temperatures under the impact of light. UV light supports the formation of radicals and therefore speeds up rancidity. Different types of fat develop rancidity at different speeds. Fatty pork meat, or pork fat, should not be stored longer than 3–4 months at  $-18\text{ }^{\circ}\text{C}$  whilst 6 months are the maximum for fatty beef, or fatty lamb meat, stored at  $-18\text{ }^{\circ}\text{C}$ . Lean meat, because of the low content in fat, can be stored for up to 1 year at  $-18\text{ }^{\circ}\text{C}$ .

Rancidity is measured chiefly in the following ways

- 1 *Number of peroxides.* Peroxide value (PV), or oxidative rancidity, measures the number of peroxides present in fat. Therefore, fat has to be isolated and other components, such as protein, removed to the utmost extent as those non-fat components can interfere during the analysis, which is a

titration process. Measuring the number of peroxides is also commonly performed on pure fats and oils and shows the stage of oxidation, or how far oxidation has progressed already as peroxides are the first components formed during the oxidation of fat. The peroxide value is helpful in order to determine the quality of saturated fat but is not that helpful in assessing unsaturated fats. Peroxides formed in unsaturated fats such as pork and chicken fat contain quite a large amount of unsaturated fatty acids, are unstable and quickly react further into secondary oxidation substances. Therefore, obtaining an accurate reading on the number of peroxides is difficult. Peroxides themselves do not show sensory characteristics that are related to rancidity but are intermediate substances which react further to become ketones and aldehydes, the main odorous substances in rancid fat. As a result, the number of peroxides found in unsaturated fat can be low even though the fat is already in a high state of oxidation. Even severely rancid fats can exhibit a low number of peroxides owing to those secondary reactions.

The number of peroxides and hydroperoxides generally formed in the early stage of oxidation is expressed in milliequivalents of peroxide per kilogram of fat (meq/kg). The formation of peroxides takes place at a slow rate during initial stages of oxidation depending on the storage temperature and the presence of antioxidants but, once a 'critical mass' is obtained, the increase in peroxides takes place exponentially. PVs from 0 to 6 are generally seen when fat is not rancid whilst PVs from 7 to 10 are seen when fat is slightly rancid. PVs greater than 10 clearly indicate rancidity but it should be kept in mind that the PV does not always directly relate to the state of rancidity (as explained above).

- 2 *Determination of the thiobarbituric acid (TBA) value.* This method is widely applied in meat products and the TBA value equals the milligrams of malonaldehyde per kilogram of sample. The amount of malonaldehyde is determined in a photometric way and rancidity starts at 0.4–0.6 mg of malonaldehyde per kilogram of sample. Within this test, saturated aldehydes obtained during the termination phase of fat oxidation react with 2-thiobarbituric acid. TBA-value analysis is performed on the food overall and not on fat only, in contrast with the peroxide number or free-fatty-acid (FFA) tests (see below). TBA values generally correlate with the state of rancidity and increased values indicate an advanced state of rancidity.
- 3 *Analysis of the FFA content.* Analysing the FFA content is based on measuring hydrolytic rancidity in fat or oil. This type of analysis is performed on fat only, and hydrolytic rancidity originates from the hydrolysis of triglycerides in the presence of moisture. Enzymes such as lipase generally speed up this process and the hydrolysis results in FFA. The FFA values generally increase during storage of fat, or fatty meats, but oxidative rancidity has a greater impact on rancidity as hydrolytic rancidity. Hydrolytic rancidity is expressed generally within fat from

meat or meat products in percentage of oleic acid and other fats, showing a high degree of shorter-chain fatty acids (coconut oil) as percentage of lauric acid. FFA values in meat and meat products above 1.2 indicate rancidity.

Other, not commonly applied methods to determine rancidity are the determination of the hexanal value, the total oxidation volume and the oxidative stability index (OSI) test. Hexanal is an aldehyde produced during the termination phase of fat oxidation and is measured via a distillation process or by carrying out a gas chromatography analysis of the headspace over a sample. The amount of hexanal determined correlates with sensorial spoilage and a concentration beyond 6 ( $\mu\text{g}$ ) per kilogram of product indicates rancidity.

By determining the total oxidation volume, which is predominantly applied by pure fats and oils, a 5 g sample is exposed to oxygen until no more oxidation takes place within the sample. The total amount of oxygen utilized during the process is expressed in milliequivalents per oxygen per 5 g of fat or oil and is determined in a volumetric way. Another predictive test towards fat oxidation would be the OSI test.

### 1.10 Low-density lipoprotein and high-density lipoprotein cholesterol

Low-density lipoprotein (LDL) is known as the ‘bad’ cholesterol (Fig. 1.23), because high levels of LDL within blood increase the risk of heart disease significantly. The level of LDL should be less than 4 mmol per litre of blood, and linoleic acid is the fatty acid most commonly transformed into cholesterol. ‘Hard’ fats exhibiting predominantly saturated fatty acids generally increase the level of ‘bad’ LDL cholesterol. To a small degree, very-low-density lipoprotein is present in the blood as well. HDL is known as the ‘good’ cholesterol and is protective against heart disease. The level of HDL in blood should be 1 mmol per litre of blood or above. Monounsaturated fatty acids, such as oleic acid, and polyunsaturated fatty acids, such as linoleic acid, reduce the level of LDL cholesterol and should be a constant part of the human diet. Pork fat contains around 55% unsaturated fatty acids and oleic acid is a significant part of it. Oleic acid also gives olive oil its ‘healthy’

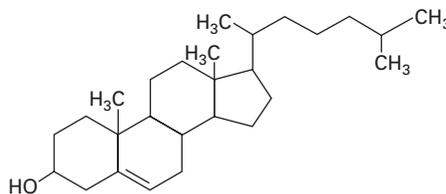


Fig. 1.23 Cholesterol.

**Table 1.1** Nutritional values of some foods (per 100 g)

	Energy (kJ)	Protein (g)	Fat (g)	Cholesterol (mg)
Lean beef	450	21.6	2.9	58
Lean lamb	501	20.4	4.2	67
Lean pork	438	21.6	2.9	66
Skinless chicken	466	20.4	3.1	89
Pork fat	3205	2.8	89.5	61

status. On the contrary, butterfat, which enjoys a more 'healthy' reputation than pork fat, contains only around 30% unsaturated fatty acids but at the same time around 60% saturated fatty acids which increase the risk of LDL cholesterol.

### 1.11 Nutritional value of meat and other protein-rich food

As the number of overweight and obese people is increasing almost worldwide, several 'super-diets' have been introduced to lose much weight rapidly. Eating a healthy and mixed diet at moderate levels, in combination with regular exercise, is the best form of prevention from being overweight, or obese. From a nutritional standpoint, 1 g of protein, fat and carbohydrates have the following energies.

- 1 Fat, 34 kJ
- 2 Protein, 17 kJ.
- 3 Carbohydrates, 17 kJ.

In the past, kilocalories were used and 1 kcal = 4.186 kJ. Table 1.1 shows the composition of some foods per 100 g of food.

The assumption that lean white meat, such as poultry, is healthier than lean red meat cannot be scientifically supported. In almost all cases, humans consume meat in a way that proteins are denatured, via a form of heat treatment, drying, salting or others. Once proteins are denatured, the digestibilities of different proteins becomes more or less the same.

The health status of meat refers more precisely to the level of fat present within and connected to meat as well as the concentration of saturated fatty acids. Increased levels of saturated fatty acids within food generally lead to increased levels of LDL cholesterol. The biological value of meat protein is around 0.73 (that of human milk is 1.0) and the protein utilization is 81 (that of egg is 100). Digestibility of meat proteins is very similar to that of egg protein and is around 95% compared with around 84% for plant proteins. Lean muscle tissue contains around 70 mg of cholesterol per 100 g of tissue and that is quite low compared with, for example, liver or kidney, which have around 420 mg of cholesterol per 100 g of tissue.

## 2

## The biochemistry of meat

## 2.1 Biochemical processes in meat pre-slaughter

In pre-slaughter muscle tissue, as long as the animal is alive and therefore breathing, muscle contraction and relaxation can take place in an aerobic way in the presence of oxygen. During muscle movement, the filaments actin and myosin slide into each other and chemically link and unlink, causing the muscles to contract as well as relax. Energy in the form of ATP is required to bind myosin into actin as well as to separate myosin from actin afterwards.

The formation of ATP (Fig. 2.1), the ultimate source of energy, is a highly complicated process and ATP is normally present in muscle tissue at a level of around 5–6  $\mu\text{mol}$  per gram of tissue. A molecule of ATP consists of a D-ribose (sugar), adenine and three phosphate groups. Similar compounds are ADP and adenosine monophosphate, which have two phosphate groups or only one phosphate group respectively within the molecule.

ATP hydrolyses easily to ADP, a single phosphate unit, and energy. The chemical energy obtained is utilized for all energy-consuming processes

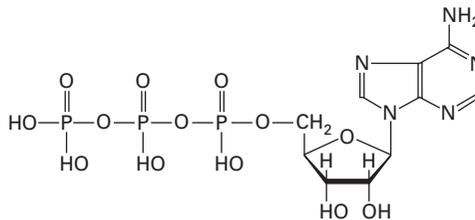


Fig. 2.1 ATP.

within the living organism as well as for the movement of muscle fibres. Excess glucose is stored in muscle tissue and in the liver in the form of glycogen as well as CP and is converted into energy if required. Hence, if all excess energy were stored in the form of ATP directly, the muscle would be in a state of permanent contraction. CP is required at times when insufficient ATP is formed or during times when ATP has to be provided instantly. ATP can be quickly synthesized in such situations and CP binds quickly with ADP to form ATP ( $\text{CP} + \text{ADP} \rightarrow \text{creatinine} + \text{ATP}$ ).

The formation of ATP whilst the animal is still alive and breathing can take place via the utilization of glucose, proteins or fat. All those materials can be transformed into acetyl coenzyme A (acetyl CoA), which is the substance that enters the citric acid cycle. Carbohydrates, however, are primarily utilized for rebuilding ATP and glycogen is readily broken down to glucose when required for energy. Fat or proteins are utilized for the formation of ATP when no more carbohydrates are available.

The process of rebuilding of ATP can be divided into three steps.

- 1 Glycolysis is the oxidation of glucose to pyruvate with the formation of some ATP and energy-rich coenzymes such as NADH from nicotinamide adenine dinucleotide ( $\text{NAD}^+$ ).
- 2 Within the second step, pyruvate is transformed into acetyl CoA which enters the Krebs or tricarboxylic acid cycle and is ultimately oxidized into carbon dioxide and water. Within this process, substances such as guanosine triphosphate (GTP) as well as energy-rich reduced coenzymes such as NADH and  $\text{FADH}_2$ , which is formed from flavin-adenine dinucleotide (FAD), are obtained.
- 3 Thirdly, NADH and  $\text{FADH}_2$  are oxidized within the oxidative phosphorylation. When electrons are passed from one carrier to another, this results in the formation of free energy, which is utilized to synthesize ATP.

### 2.1.1 Glycolysis

Glycogen, the muscular sugar and a polysaccharide, has a molecular mass of 6–12 MDa and muscle tissue contains around 0.7–1.1% glycogen. Muscle tissue also contains around 10–25 g of free glucose per 100 g of tissue. Glycogen is only found in animals and can be seen as the equivalent storage carbohydrate to starch in plants. Glycogen is a polymer of D-glucose and is identical with amylopectin found in starch, but the branches in glycogen tend to be shorter (about 10–12 glucose units) and more frequent than in amylopectin. The glucose chains are organized globularly and glycogen can be converted back to glucose quickly. The two forms of glycogen, commonly referred to as glycogen for reasons of simplicity, are proglycogen and macroglycogen. Proglycogen accounts for around 75% of the total glycogen whilst macroglycogen makes up the remainder.

Glycogen is converted easily into glucose, which is then broken down by glycolysis, also known as the Embden–Meyerhof pathway. The process of glycolysis is the oxidation of glucose to pyruvate, which takes place in the sarcoplasm (cytoplasm) of a cell and is heavily regulated by enzymes. It is an anaerobic process and therefore no oxygen is required. During glycolysis, glucose is turned into pyruvate by first being turned into glucose-6-phosphate. Glucose-6-phosphate is then transformed into fructose-6-phosphate and ten steps are needed in total in order to obtain pyruvate, which is the end point of glycolysis.

One molecule of glucose entering glycolysis turns into two molecules of pyruvate as glucose is a six-carbon molecule and pyruvate is a three-carbon molecule. Pyruvate is finally converted into acetyl CoA by the loss of one molecule of CO<sub>2</sub> to become a two-carbon molecule in a process known as decarboxylation. This transformation is supported by the enzyme pyruvate dehydrogenase, and acetyl CoA is occasionally referred to as ‘activated acetic acid’. Splitting of glucose during glycolysis is an exergonic process, meaning that energy is released during the process. Within glycolysis, two molecules of ATP are utilized but four molecules of ATP are gained. Therefore, the net gain from glycolysis is two ATP molecules per molecule of glucose.

When there is an oxygen deficiency during periods of instant need of high levels of ATP (such as heavy muscular work or in a very stressful situation), ATP is obtained anaerobically and lactic acid is formed as a by-product in the living organism. This organic acid is then transported in the bloodstream back to the liver, where lactic acid is converted firstly into glucose-6-phosphate and finally into glycogen or glucose.

Proteins are generally not used to obtain ATP but, in times of great need, e.g. when further carbohydrates are not available, proteins are also converted into acetyl CoA. Within such very rare situations, proteins are broken down in the first place into amino acids, which are then converted in a second step into acetyl CoA. This process is called deamination and the amino group of an amino acid is removed. Subsequently, the amino group is converted into an ammonium ion (NH<sub>4</sub><sup>+</sup>), which is removed from the cell. The remaining part of the amino acid can then enter the Krebs cycle. Proteins are, as stated, the last resource for obtaining energy, given that proteins are too valuable to be transformed into energy. The body utilizes carbohydrates (and fat) first, whereas proteins are the very last resort.

In cases where fat is broken down for the formation of ATP, glycerol is turned into aldehyde phosphate together with fatty acids, which are then oxidized several times, also ending up as acetyl CoA. The formation of pyruvate is the end point of anaerobic glycolysis in the cytoplasm utilizing glucose before pyruvate is turned into acetyl CoA. In effect, all materials such as amino acids (from proteins), fatty acids and glycerol (from fat) and pyruvate (from glycogen) end up in the form of acetyl CoA, but by far the most important material is glucose. Proteins and fat are transformed directly

to acetyl CoA, whereas glucose is, as stated above, transformed first into pyruvate before then being turned into acetyl CoA.

### 2.1.2 Krebs cycle

This biochemical cycle, also known as the tricarboxylic acid cycle or citric acid cycle, is named after the Austrian scientist Hans Krebs, who researched this highly complex process. The citric acid cycle is a sequence of reactions in which two-carbon molecules of acetyl CoA, originating from pyruvate (or proteins and fat), are entirely oxidized to carbon dioxide and water. This biochemical process occurs in the mitochondria of a cell and oxygen is required for this aerobic process. Free hydrogen atoms are obtained during the citric acid cycle, which bind to coenzymes such as  $\text{NAD}^+$  and are then reduced to NADH as a result. Hence, other coenzymes such as FAD also take up free hydrogen and are reduced to  $\text{FADH}_2$ . Those reduced coenzymes contain more energy than in their non-reduced state, and this energy is used in the last step of oxidative phosphorylation to synthesize ATP from ADP.

The major steps within the citric acid cycle (Fig. 2.2) are as follows.

- 1 Catalysis of acetyl CoA to citrate with the help of the enzyme citrate synthase.
- 2 Catalysis by aconitase, another enzyme, of citrate into isocitrate.
- 3 Decarboxylation of isocitrate into  $\alpha$ -ketoglutarate by isocitrate dehydrogenase as well as reducing  $\text{NAD}^+$  to NADH.
- 4 Production of succinyl-CoA by  $\alpha$ -ketoglutarate dehydrogenase and reduction of  $\text{NAD}^+$  to NADH within this step.
- 5 Transformation of succinyl CoA into succinate by the enzyme succinyl CoA synthetase, obtaining GTP as well.

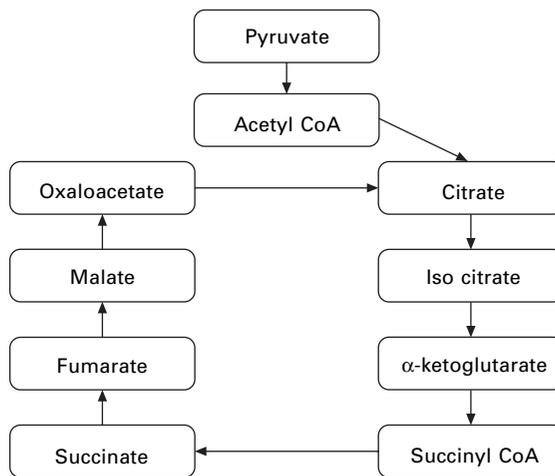


Fig. 2.2 The Krebs cycle.

- 6 Oxidation of succinate to fumarate by succinate dehydrogenase and reduction of FAD to FADH<sub>2</sub>.
- 7 Hydration of fumarate to malate by fumarase.
- 8 The last step within the citric acid cycle: transformation of malate into oxaloacetate with the help of the enzyme malate dehydrogenase by another reduction of NAD<sup>+</sup> to NADH.

For every two molecules of acetyl CoA entering the Krebs cycle, four molecules of carbon dioxide are liberated via decarboxylation. In addition, two molecules of FADH<sub>2</sub>, six molecules of NADH and two energy-rich molecules of GTP are obtained. The formation of the coenzymes NADH and FADH<sub>2</sub>, from NAD<sup>+</sup> and FAD respectively, is the most important process of the Krebs cycle as these reduced coenzymes contain much energy, which is utilized in a series of reduction as well as oxidation processes within the subsequent step of oxidative phosphorylation for the rebuilding of ATP. One molecule of NADH results in the formation of three molecules of ATP whilst one molecule of FADH<sub>2</sub> generally results in the formation of two molecules of ATP.

### 2.1.3 Oxidative phosphorylation

The third step within the entire process of rebuilding ATP is oxidative phosphorylation, where reduced coenzymes such as NADH and FADH<sub>2</sub> are oxidized with the help of oxygen; this is why animals and humans have to respire. Oxidative phosphorylation also takes place in the mitochondria of a cell. Hydrogen is split into protons and electrons, and electrons are passed to oxygen and other inorganic compounds. In a series of reactions, electrons are passed from one carrier to another within the process of oxidative phosphorylation in what is known as the electron-transfer chain (ETC). Water is split off during this process and the reoxidation of NADH, as of well as FADH<sub>2</sub>, or the transfer of electrons from one electron carrier to the next, releases energy, which is ultimately utilized for the formation of ATP from ADP and phosphate. The process of ATP synthesis using 'free energy' obtained when electrons are passed to several carriers (ETC) is known as chemiosmosis. The actual point of the synthesis of ATP takes place when electrons pass the inner mitochondrial membrane. Energy is released within this process, resulting in the synthesis of ATP. Oxidative phosphorylation could be summarized in the following way: Reduced coenzymes NADH + FADH<sub>2</sub> + oxygen → ETC → oxidized coenzymes NAD<sup>+</sup> + FAD + water + free energy → ADP → ATP.

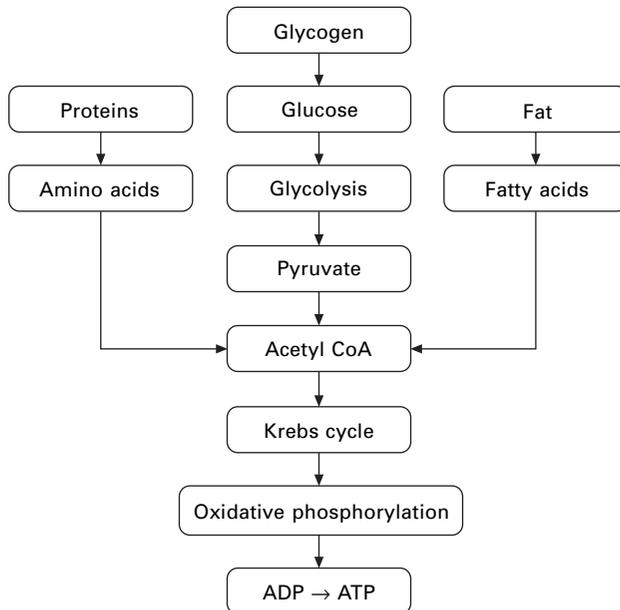
Thirty-two molecules of ATP are obtained during oxidative phosphorylation per molecule of glucose. Together with the two molecules of ATP resulting from glycolysis, as well as the two molecules of GTP from the Krebs cycle (which can be readily transformed into ATP and can be counted as ATP), 36 molecules of ATP are obtained in total per molecule of glucose.

Some enzymes can only function in conjunction with coenzymes. Coenzymes are not protein based and can be nucleotides, ions or vitamins and, when these nucleotides, ions or vitamins are bound loosely to an enzyme, a coenzyme is obtained. One of the most important tasks of a coenzyme is to carry over, or to pass on, hydrogen and electrons and energy within biochemical processes. Substances, such as nucleotides, act as carrier materials for hydrogen and electrons. Nucleotides such as  $\text{NAD}^+$  and  $\text{FAD}$ , both coenzymes, are reduced by the uptake of hydrogen, resulting in  $\text{NADH}$  as well as  $\text{FADH}_2$ .

As explained above, in pre-slaughter muscle tissue, as long as the animal is alive and therefore breathing, the filaments actin and myosin slide into each other and muscle contraction, as well as relaxation, takes place promoted by aerobically formed ATP (Fig. 2.3). Availability and utilization of ATP break down the actomyosin complex, obtained during contraction, into the separate fibres of actin and myosin once again. The pH value of lean muscle tissue at this stage, in the living animal, is between 6.8 and 7.2. Pork fat exhibits a pH of 6.3–6.6 at the point of slaughter and beef lard a pH value of around 6.8.

## 2.2 Biochemical processes in meat post-slaughter (rigor mortis)

Post-slaughter, chemical changes in muscle tissue due to the absence of oxygen result in a situation where actin and myosin are not present as separate



**Fig. 2.3** The process of obtaining ATP under aerobic conditions.

fibres any longer but are bound together in the actomyosin complex. Muscle tissue ultimately remains contracted and processes leading to that state are known as rigor mortis. Rigor mortis, from Latin and meaning 'stiffness of death', eventually subsides to relaxation of muscle tissue once insufficient energy is rebuilt and when energy present in muscle tissue at the point of slaughter is primarily decomposed to lactic acid. The biochemical processes in meat post-slaughter leading to rigor mortis and subsequent stages are explained below.

### **2.2.1 Anaerobic glycolysis and the formation of lactic acid**

Once the animal is slaughtered, since respiration ceases, no further oxygen enters the body. Muscular sugar glycogen, present at the point of slaughter in muscle tissue, is converted anaerobically after slaughter into pyruvate, just as it is during glycolysis whilst the animal is still alive, as this step occurs anaerobically regardless of whether the animal is alive or dead; the absence (or presence) of oxygen does not play a role at this point. Furthermore, any remaining CP in muscle tissue at the point of slaughter is also used during post-mortem glycolysis to turn ADP into ATP under anaerobic conditions. Most of the post-mortem glycolytic enzymes are located near the F-actin, which is part of the I band.

The major difference between aerobic and anaerobic glycolysis is that the pyruvate obtained from glucose is not converted into acetyl CoA in anaerobic glycolysis as the oxygen required for this step is no longer available. As a result, no acetyl CoA enters the citric acid cycle to create reduced coenzymes such as NADH and FADH<sub>2</sub>, and oxidative phosphorylation also does not take place. Instead, pyruvate is reduced predominantly to lactic acid (lactate<sup>-</sup> and H<sup>+</sup>) under anaerobic circumstances and this is catalysed by the enzyme lactate dehydrogenase.

The level of glycogen in muscle tissue prior to slaughter is around 7–11 g per kilogram of muscle tissue and lactic acid is formed at an amount of 38 molecules per molecule of glucose in post-mortem glycolysis during rigor mortis. The lactic acid formed is not transported back to the liver, as happens whilst the animal is still alive, and therefore the concentration of lactic acid within muscle tissue increases steadily after slaughter. As a result, the pH of muscle tissue declines during rigor mortis by around 1.5–1.7 pH units owing to the accumulation of lactic acid from approximately 7.0 (in the living animal) down to around 5.4.

A tiny amount of ATP, however, is still obtained anaerobically post-slaughter. Only three molecules of ATP are obtained from one molecule of glucose during post-mortem glycolysis, compared with 36 molecules of ATP during aerobic glycolysis, representing just one twelfth compared with aerobic glycolysis. The effects of the three molecules of ATP obtained in an anaerobic state can be observed on the carcass as there is visible fibre movement even though the animal is already dead.

Post-mortem glycolysis can be inhibited or comes to an end in two possible ways. Firstly, when no more glycogen or glucose is present within the meat, no further pyruvate is formed and therefore cannot be subsequently turned into lactic acid any longer. Secondly, when during glycolysis the pH value has declined to around 5.3–5.4, even though some glucose is still present in the muscle tissue, the glycolytic enzymes cease to function at such low pH values. Anaerobic glycolysis can be summarized in the following way: glycogen → glucose → pyruvate → reduction of pyruvate → lactic acid → only three molecules of ATP, but 38 molecules of lactic acid are obtained from one molecule of glucose.

Formation of lactic acid during post-mortem glycolysis is responsible for the decline in pH value within the meat after slaughtering. The pH value of meat at the point of slaughter varies depending on the type of animal but is generally between 6.8 and 7.2. After slaughter, the pH normally drops to around 5.3 – 5.4, which is close to the IEP of muscle meat. Upon completion of post-mortem glycolysis, the final pH value of red meat is slightly higher than that of white meat; red meat generally contains slightly less glycogen than white meat at the point of slaughter and, as a result, the pH value does not decline as much during rigor mortis. High final pH levels in meat after completion of post-mortem glycolysis and rigor mortis correlate with the low level of glycogen present at the point of slaughter in muscle tissue, leading to insufficient acidification of muscle tissue post-slaughter, which results in a final pH value of around 6.2–6.4 (DFD meat).

### **2.2.2 Adenosine triphosphate levels post-slaughter and rigor mortis**

In living muscle, the level of ATP is around 5  $\mu\text{mol}$  per gram of muscle tissue and levels as low as 1.5  $\mu\text{mol}$  per gram of muscle tissue are sufficient for contraction and relaxation of the muscle fibres. The level of ATP remains unchanged for a short time after slaughter as ATP is rebuilt anaerobically by CP binding to ADP to generate ATP. After a certain period of time post-slaughter (in pork after about 2–4 h, in chickens 1–2 h and in cattle 4–8 h), the concentration of ATP in muscle tissue drops below 1  $\mu\text{mol}$  per gram of muscle tissue. At this point, meat exhibits a pH value of around 6.0 and  $\text{Ca}^{2+}$  ions are no longer absorbed by the SPR. At such low levels of ATP, actin and myosin do not dissociate any longer and instead remain bound together to form the actomyosin complex. This point marks the onset of rigor mortis and the warm-meat effect (WME) (see Chapter 4, Section 4.3) is lost. In rigor mortis, the head of the myosin filament ‘locks’ into the actin and permanent ‘cross-links’ are established between the two filaments by not separating any longer as no, or insufficient, ATP is provided. Upon completion of post-mortem glycolysis, most actin and myosin filaments are cross-linked to form the actomyosin complex.

Post-mortem glycolysis generally takes place more slowly in cattle than in pigs. Certain breeds of pigs, such as Pietrain and German Landrace, tend

**Table 2.1** Differences in meat pre-slaughter and post-slaughter

	pH	WHC	Solubility of protein
Pre-slaughter	6.8–7.2	Excellent	Excellent
Post-slaughter	5.3–5.4	Poor	Poor

to undergo very fast post-mortem glycolysis and therefore are prone to developing meat with PSE character. Rigor mortis is complete in beef after around 24–40 h and in pigs after around 8–16 h. In poultry, such as chicken, it takes only 2–4 h until rigor mortis is completed: chicken breast especially can demonstrate extremely fast rigor mortis. In extreme cases, rigor mortis is completed within 1–1.5 h after slaughtering in chicken breast.

Upon completion of post-mortem rigor mortis, the pH value has dropped to around 5.3, and actin and myosin are present as the actomyosin complex, contrary to the situation when the animal was still alive (Table 2.1). WHC and solubility of muscular protein are greatly reduced as a result of those changes. From this point onwards, meat enters the stage of maturing, also known as ‘ripening’, and tenderization starts to take place as the decline in pH value releases enzymes responsible for tenderness (see Chapter 3, Section 3.1).

## 3

# The tenderness of fresh meat

The tenderness of meat ranks as the second most important criterion to ensure repeat customer purchase of meat, the first being attractive colour and appearance. A lack of tenderness in meat is caused by a combination of toughness in the fibre structure of meat and toughness in the connective tissue. The degree of toughness of meat can predominantly be linked to the age of the animal and to a small degree to the species of animal. Muscle tissue of older animals shows signs of an increased number of cross-links between actin and myosin as well as increased numbers of cross-links within collagen (see Chapter 1, Section 1.3).

To obtain tender meat, a certain temperature–pH relationship should be adhered to post-slaughter; the pH value must be at or below 5.7 once a temperature of 7 °C is present within meat. If the meat or carcass cools too quickly and the temperature is below 7 °C, once a pH value of 5.7 is reached, there is a risk of cold shortening. To avoid cold shortening, another temperature–pH relationship to be observed is that the internal temperature of meat must not be below 14 °C if the pH is still at 6.2 or above (see Chapter 4, Section 4.5). Of course, a carcass must also not be cooled too slowly for microbiological reasons; microbial growth must be kept under control.

### 3.1 Ageing of meat for enhancing tenderness

Tenderness of meat is related to a combination of breakdown within muscle fibres, predominantly due to the activity of enzymes, and loosening of connective tissue, specifically collagen. Collagen in raw meat is usually loosened by the enzyme collagenase over a prolonged period of time but this

process takes place only to a small degree as the action of collagenase is very slow and meat would be microbiologically spoiled before collagen would be significantly softened. Another method of softening collagen in raw meat is to place meat in a sour (acidic) soaking solution containing wine and/or vinegar under chilled conditions for 24–48 h as practised during the preparation of meat dishes in countries such as Germany (Sauerbraten). Collagen exposed to a sour environment starts to swell, thus taking up moisture and loosening the collagen structure is the result. As discussed in Chapter 3, the toughness in meat is the combination of toughness in muscle and the toughness in connective tissue.

Naturally occurring enzymes in meat, predominantly cathepsins (which are cysteine proteases) tenderize meat by slowly breaking down the muscle fibres. Cathepsins are found in the lysosomes of a muscle cell, protected by a wall of fat, and over 30 different enzymes are involved. During rigor mortis, as a result of the formation of lactic acid and therefore the decrease in pH value, the walls of fat are destroyed by the impact of lactic acid, and cathepsins are released. Cathepsins work on the bonds between actin and myosin and contribute greatly to the tenderness of meat.

Calpains (calcium-activated proteases), which are present in the sarcoplasm is another type of enzyme naturally present in meat, contribute to the tenderization of meat in a different way; these enzymes cut along the Z lines and long fibres are ‘cut’ into smaller units. The level of enzyme activity is largely determined by the temperature that meat is stored under as well as the level of enzymes naturally present in meat. Calpains are known to work more effectively at higher pH values in meat such as 6.2–7.0, while cathepsins prefer a lower pH value around 5.4–5.9. This leads to the assumption that calpains are more important during the early stage of post-mortem glycolysis than are cathepsins, which seem to act later in the process. It is not fully understood yet the degree to which each enzyme ultimately contributes to overall tenderness, but it is thought that both types of enzyme, namely calpains and cathepsins, act synergistically towards enhancing the tenderness of meat.

Another contributing factor to the tenderness of meat is the loosening of the actomyosin complex. During maturing of meat, actin and myosin remain to a large degree cross-linked together as the actomyosin complex and are therefore responsible only to a small degree for the tenderness of meat. The impact of enzymes such as cathepsins and calpains on the toughness of collagen is insignificant.

During ageing, the visual appearance of meat does not change, given that breakdown of muscle fibres takes place on a microscopic level. Meat can age without being packed for up to 14 days depending on the microbiological status of the meat and the storage temperature. Vacuum-packed meat can age for up to 3 months as aerobic spoilage bacteria are kept away effectively.

The speed of tenderization varies dramatically between different species and ageing of beef requires a significantly longer time than pork and chicken in order to achieve a comparable degree of tenderness. The reason for this is

that pork and chicken contain a significantly higher level of proteolytic enzymes such as cathepsins and tenderization occurs in pork and chicken at a significantly faster rate as a result. In order to obtain a tender piece of beef, stored between 0 and 3 °C, at least 2 weeks are needed. A similar tenderizing effect can be seen in pork within 2–3 days at the same storage temperature. On the other hand, a comparable effect on tenderness in poultry can be seen within 1–2 days. Lamb lies somewhat in between beef and pork and generally requires around 7–10 days in order to become tender. The 'speed of tenderization' between 4 and 45 °C is 85 times faster; meat exposed for 1 h to a temperature of 45 °C would need to tenderize for 85 h at a temperature of 4 °C in order to demonstrate similar tenderizing enzyme activity. This fact is often utilized in restaurants where chefs place raw meat, which is shortly to be prepared, in the oven at the above-mentioned temperatures to speed up tenderization.

The pH value of meat rises significantly during ageing owing to the formation of alkaline metabolic by-products of enzyme activity, which eventually lead to spoilage. Once the pH value exceeds 6.4–6.5, meat is spoiled from a sensorial point of view as high levels of ammonia (NH<sub>3</sub>) and other metabolic by-products are produced. Formation of slime is observed commonly at this stage and discolouration also takes place at this point.

If deboned meat is aged whilst vacuum packed, this has the benefit that anaerobic bacteria, such as *Lactobacillus* spp., have an advantage over aerobic spoilage bacteria. Because of the degree of acidity obtained within the vacuum-packed meat, the collagen swells, resulting in softening of the connective tissue. When meat is vacuum packed, contamination via handling is also avoided, extending the shelf life of the product.

Research has been carried out to investigate whether injecting a calcium chloride or enzyme solution into living animals (e.g. cattle) shortly before slaughter increases the tenderness of meat after slaughter. The results, however, were not convincing and the meat even exhibited a slight bitter taste after this treatment.

Beef can be tenderized by the application of the tender-stretch method: hanging the halves of carcasses straight after slaughter by the hip or pelvic bone. Gravity pulls down on both ends of the carcass and therefore the muscles cannot contract as severely as they would if the carcass were hung the conventional way, vertically from the Achilles tendon. Because of this counter-force, a reduced number of cross-links between actin and myosin are formed and the degree of toughness is reduced. However, the technique of hanging the carcass on the pelvic bone is not used as often as the technique of hanging on the Achilles tendon, given that the space needed per half of a carcass is significantly more than if the carcass is hung on the Achilles tendon. Cutting up a carcass hanging on its pelvic bone into a forequarter and a hindquarter is also more difficult compared with cutting up a carcass hanging on its Achilles tendon. Another occasionally practised method is to hang half of a carcass (cattle) on the pelvic bone first for several hours for

the above-mentioned reasons and then to hang it on its Achilles tendon during further cooling and maturing.

Another means of tenderizing meat is steaking or scoring. Fine needles introduced into the muscle meat literally 'cut' fibres into smaller units. Such smaller units of muscle fibres require less shearing or chewing forces and the meat appears tender. Yet another means of tenderizing meat is to thaw frozen meat, as ice crystals are formed during freezing of meat. Ice crystals have sharp edges and also 'cut' fibres into smaller units, which enhances tenderness slightly.

### **3.2 Enzymes used for enhancing the tenderness of meat**

Enzymes have been used to tenderize meat for hundreds of years. One of the most common enzymes applied is papain and the origin of this enzyme is papaya, a fruit grown in tropical countries. Papain is usually produced as a crude dried material by collecting the latex from the fruit of the papaya tree. This latex is further dried and purified and papain is sold in liquid and powdered form. The enzyme is totally inactivated at a temperature of 82 °C and the optimum pH of papain is similar to that of meat itself. The application of papain has to be tightly controlled. If papain is left to tenderize meat for a long period of time, the result will be a structureless piece of meat with no texture and bite at all.

Other enzymes occasionally applied are ficin, from the milky juice of the fig tree, and bromelain. Bromelain originates from the stump or root of the pineapple plant after harvest of the fruit. The stump is peeled and crushed to extract the juice, which contains the enzyme. Bromelain is sold in powdered form. Contrary to papain, bromelain and ficin also enhance the tenderness of connective tissue, while papain focuses almost solely on the tenderness of meat. However, bromelain or ficin are hardly used. Ginger root also tenderizes meat but is not used commercially.

The major disadvantage of all these 'natural' tenderizers is that, if they are applied in a slight overdose, or if the tenderization process is too lengthy, the tenderizing effect becomes very strong and the entire fibre structure of the meat is destroyed. Meat exhibiting a mushy soft texture, with no or little bite, is the result of such excessive enzyme activity.

## 4

# Definitions of terms used in meat science and technology

### 4.1 Pale soft exudative (PSE) meat, red soft exudative (RSE) meat, dry firm dark (DFD) meat and 'normal' meat

#### 4.1.1 Stunning and stress

Proper handling of animals and birds prior to slaughter has a tremendous impact on the quality of meat obtained and nowadays there is much research and investment into abattoir design and construction. Even the input of specialists such as animal psychiatrists is vital to establish a well-functioning and efficient slaughtering process. The fact of the matter is that, if the 'functional quality' of the meat is destroyed during the slaughtering and cooling process, neither the use of an additive nor processing with modern equipment can remedy this damage afterwards.

Stunning with the help of carbon dioxide (CO<sub>2</sub>) is the preferred method nowadays for knocking out pigs, because the pigs lose consciousness gently and, in comparison with electrical stunning, much less internal muscle bleeding occurs and fewer bones are broken. The pigs are placed in a cage and lowered into a chamber where the concentration of carbon dioxide gradually increases and remains at a high concentration for a certain period of time. Stunning pigs using a gas such as argon is an even more gentle way to knock out pigs and an improved quality of meat could be obtained using this method. However, stunning pigs with argon is in its infancy and further research as well as testing is required. It is also usually more expensive to use argon than carbon dioxide. To avoid acute 'stress' before slaughtering, gentle showers, such as a fine mist, are sprayed over the pigs to keep them 'cool' and waiting areas are of light-blue or light-green colour, which also calms pigs down. In addition, when pigs have to walk to the stunning area on their own feet, they prefer to

walk slightly uphill, and they walk faster if they are walking towards a well-lit area; so abattoirs often are designed with this in mind. Research continues to find better and more efficient ways to improve both meat quality as well as slaughtering efficiency.

Selective breeding and especially over-breeding in pigs nowadays has produced significantly larger amounts of muscle meat in breeds such as Pietrain and German Landrace, and others, compared with 20 years ago. The aim of selective breeding is to maximize growth of the high-value cuts of a pig such as the loin and the leg. Muscle tissue needs to be supported by much oxygen and the skeleton as well as the size of the heart from pigs has stayed the same over the same period of time while the amount of muscle tissue increased dramatically. As a result, overbred animals are very sensitive to 'stress' or stressful situations.

#### **4.1.2 Pale soft exudative meat, red soft exudative meat and dry firm dark meat**

Pale soft exudative (PSE) meat is the term used to describe a defective type of meat, seen predominantly in pork, but also in poultry. Unfortunately it is high-value cuts, such as loin and leg meat, that are predominantly affected and it is the degree of the PSE condition of meat which is crucial, as the borderline between PSE and non-PSE meat is not clearly defined.

The combination of two factors, namely a low pH value shortly after slaughtering and a high temperature within meat (above 37 °C) at the same time, are the cause of the PSE condition. In acute stressful situations prior to slaughter, pigs produce lactic acid from glycogen anaerobically whilst they are still alive and they breathe heavily to form the large amounts of ATP required. The formation of lactic acid whilst the animal is still alive, in conjunction with fast post-mortem glycolysis, causes a rapid drop in pH. This results in an abnormally low pH value in muscle tissue shortly after slaughter, contributing to the formation of PSE meat. Electrical stunning of pigs most commonly speeds up post-mortem glycolysis and therefore also contributes to the formation of PSE meat. Stressful conditions prior to slaughter also cause a rise in the pigs' temperature and the temperature of meat remains high after slaughter. PSE-susceptible pigs can exhibit body temperatures of around 42 °C if heavily stressed shortly before slaughter, whereas 37 °C is the normal body temperature. A halothane test is frequently applied in order to determine PSE susceptibility in pigs. Halothane-positive pigs, commonly Pietrain and Landrace, demonstrate great tendency to produce PSE meat when the animal is not handled properly prior to slaughter.

PSE meat is usually of pale colour, wet in appearance and very soft in texture and the PSE condition is caused by partially denatured proteins. Denatured proteins cannot hold, or bind, muscular water as well as fully native proteins. More specifically, the length of the myosin filament is reduced by around 8–10% during this process of denaturation and the WHC of meat

(the capacity of meat itself to retain, or hold, its own tissue water) is greatly reduced as a result. The reduced WHC explains the fact that PSE meat appears to be ‘wetter’ than normal pork meat. In actual fact, the level of water within PSE pork is in most cases the same as in normal pork, but the WHC is reduced owing to the smaller quantity of native protein in the meat. Firmness of PSE pork is also reduced in comparison with normal pork owing to partial denaturation of proteins; denatured proteins exhibit a change in their three-dimensional structure, which leads to a less firm structure overall.

The light, or lighter, colour of PSE pork is explained by the small myofibrillar volume in the muscle tissue. Muscle tissue with a small myofibrillar volume has a high light-scattering ability; so light is reflected differently in PSE meat from normal pork. Light is unable to penetrate into the meat and so becomes scattered right on the surface; the myoglobin cannot absorb the light thus making the meat appear pale. It is an interesting fact that the colour of PSE pork is generally lighter even though the content of myoglobin in PSE pork is in most cases the same as in normal pork. The small myofibrillar volume causes the open-meat structure of PSE meat as denatured proteins shrink, thus resulting in larger gaps between the individual fibres. To some degree, myoglobin is also denatured in PSE meat, and denatured myoglobin does not contribute to the formation of curing colour in cured meat products any longer.

PSE pork can be checked 45 min ( $\text{pH}_{45}$ ) or 60 min ( $\text{pH}_1$ ) after slaughtering by checking the pH value in the muscle of the loin (*Musculus longissimus dorsi*). If  $\text{pH}_{45}$  is at 6.0, or  $\text{pH}_1$  is at 5.8, PSE meat is obtained. When  $\text{pH}_1$  is below 5.8, severe PSE pork is the result. Checking the pH value after 24 h, once the rigor mortis in pork is completed and the meat is well chilled, does not give any indication towards PSE, given the fact that in PSE pork as well as in normal pork the final pH values are more or less the same (Fig. 4.1).

Chilling pork carcasses quickly, commonly in blast chillers straight after slaughtering, helps to minimize the severity of PSE. If meat with a high pH value is chilled quickly after slaughter, the meat proteins are not damaged as much as they would be if the meat were chilled slowly. During such fast

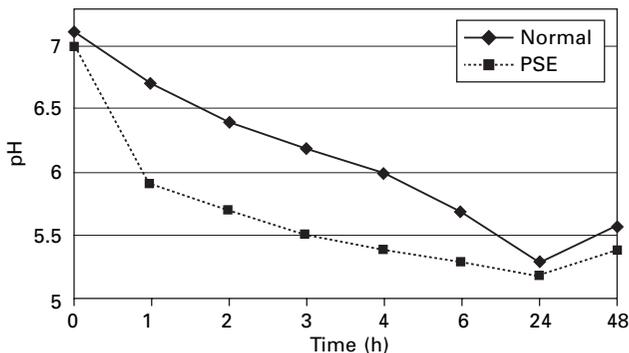


Fig. 4.1 Decrease in pH in normal and PSE pork.

chilling, a temperature in the meat of 32–35 °C is commonly reached within 90 min. Despite the possibility of obtaining a slight degree of cold shortening during ‘fast’ chilling, a slight degree of cold shortening (see Section 4.5) is of less economical disadvantage than obtaining PSE meat.

Red soft exudative (RSE) meat is another term used to describe meat that has a quality defect. RSE pork has the same characteristics as PSE pork, except that it preserves the natural red colour of meat better than PSE pork, possibly because the carcass was chilled quickly after slaughter. Light is not scattered as severely as it is under ‘more severe’ PSE conditions and so the meat appears redder in colour despite the fact that a similar amount of protein is denatured.

Neither PSE nor RSE meat offers technological advantages within the manufacture of meat products. Because of the reduced level of native proteins, WHC as well as water binding-capacity (WBC) are reduced and the ‘lighter’ colour is not of any benefit either. It is also important to emphasize that once proteins are denatured, as they are in PSE pork, no additive can make up for this shortcoming afterwards during the production of meat products and the non-functional proteins cannot be turned back into their native state. The level of PSE pork varies from country to country and some countries have as little as 2–4% PSE pork whilst others obtain 25–40% of PSE calculated from the total number of pigs slaughtered.

Dry from dark (DFD) meat is the term used for another type of defective meat; DFD meat is also known as ‘dark-cutting meat’. DFD characteristics in meat can be seen predominantly in beef as well as lamb; however, some pigs nowadays also exhibit DFD character.

Contrary to pigs, which produce lactic acid out of glycogen in an anaerobic way if exposed to ‘stress’ prior to slaughter, animals such as cattle, deer or lamb utilize glycogen in an aerobic way if stressed before slaughter. They simply burn energy (glycogen) under stressful situations for the formation of ATP and no lactic acid is obtained while the animal is still alive. As a result, insignificant amounts of glycogen are left in the muscle at the point of slaughter and no, or very little, lactic acid can be produced post-slaughter during rigor mortis. This results in an insufficient decline in pH value within meat after slaughter and upon completion of rigor mortis, by beef after around 24–36 h, the pH value in meat is still around 6.0–6.2 (Fig. 4.2). This phenomenon is also sometimes called ‘incomplete rigor mortis’ as proper and sufficient acidification within meat never takes place post mortem and a small number of cross-links between actin and myosin are established. The small number of cross-links explains the high solubility of DFD meat; the protein molecules are far less tightly bound together than they are in PSE meat or meat that has undergone a ‘normal’ rigor mortis. DFD meat demonstrates a ‘closed’ fibre structure once rigor mortis is completed and only small gaps are present between the muscle fibres actin and myosin.

Contrary to PSE meat, where the pH value has to be checked 45 min or 1 h after slaughter, DFD meat can be detected upon completion of rigor

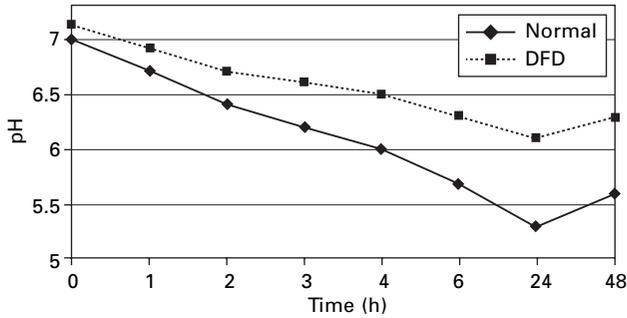


Fig. 4.2 Decrease in pH in DFD and normal beef.

mortis, in beef after around 24–36 h post-slaughter. If at this point in time the pH value is at (or above) 6.0, DFD meat is obtained. DFD meat appears dark in colour owing to the ‘closed’ fibre structure (small gaps between actin and myosin) and has a slight slimy/tacky appearance, which is not microbiological sliminess caused by high numbers of bacteria. When cutting steaks of DFD meat, butchers use the phrase ‘the meat does not come off the knife’ to describe their character.

From a technological view point, DFD meat has the advantage of high protein solubility, as acidification during rigor mortis never really took place and an actomyosin complex was only obtained to a small degree (Table 4.1). The WHC of DFD meat is also excellent; the high pH value correlates with a high WHC as the pH value of DFD meat is a long way from the IEP (pH value of 5.2). On the other hand, because of insufficient acidification of muscle tissue during rigor mortis, the shelf life of DFD meat is dramatically shortened as nearly all types of bacterium find favourable conditions for growth at elevated pH levels. Hence, the high pH value is an obstacle for the development of curing colour in cured meat products produced out of beef (see Chapter 7, Section 7.3).

In poultry, both PSE and DFD character can be found. Poultry generally enter rigor mortis very quickly and post-mortem glycolysis seems to take place more rapidly in white muscles, such as breast, compared with red muscles from the leg.

## 4.2 Mechanically deboned meat and mechanically separated meat

The terms ‘mechanically deboned meat’ (MDM) and ‘mechanically separated meat’ (MSM) basically describe the same type of meat. When discussing MDM and MSM, a distinction has to be made between ‘hard’ and ‘soft’ MDM and MSM.

**Table 4.1** Characteristics of PSE and DFD meat

Characteristic	Value or description	
	PSE	DFD
pH value	$\text{pH}_1 < 5.8$	$\text{pH}_{24} > 6.2$
WHC	Poor	Very good
Consistency of meat	Soft	Solid
Colour of meat	Pale, light	Dark
Post-mortem glycolysis	Very fast	Slow and incomplete
Shelf life of meat	Slightly reduced	Significantly reduced
Tenderness of meat	Reduced	Enhanced

Hard MDM and MSM are generally produced from meaty bones of pork and beef, from which it would be quite labour intensive to clear all meat off the bone. Hard MDM from poultry is predominantly obtained from carcasses of chicken or turkey, with the valuable parts such as wings, legs and breast removed. Bones or carcasses are exposed to high pressure in a kind of 'pressure chamber', which has small holes in it. Through the application of high pressure, carcass- or bone-attached meat, fat and skin separates from the bones and those materials pass through the barrel sieve (around 0.5–0.8 mm in diameter) whilst the bone part remains inside the barrel and is discharged separately. There are several different types of machine on the market and the basic principle is that the soft materials are separated from the hard material (bones) through the application of a high pressure.

Hard MDM and MSM should not contain bone particles within the material obtained and the amount of bones, or small fragments of bone, should not exceed 0.3%. In reality, levels of up to 4% can be found quite regularly and, hence, the content of calcium and phosphorus in hard MDM can be quite high. Enhanced levels of calcium within hard MDM can interfere with the functionality of phosphates during the production of products such as frankfurters when high levels of MDM, which is high in calcium and/or phosphorus, are utilized within the recipe. The microbiological status of hard MDM is of great importance and care has to be taken that bones and carcasses, processed for the production of MDM, exhibit a low bacteria count. MDM has a large surface area and is therefore susceptible to high levels of bacterial growth.

The bacteria count of chicken MDM is frequently higher than beef or pork MDM and the microcount is influenced greatly by the processing technology involved in combination with the level of hygiene applied during processing, as well as the bacteria count of the material to be processed. The bacteria count in hard MDM should not be higher than in ordinary minced muscle meat and should not exceed  $10^5$ – $10^6$  colony-forming units (cfu)/g. Also, the presence of bone marrow in MDM can speed up oxidation of fat, given that bone marrow contains a fair amount of metals such as iron, magnesium and copper, which act in a pro-oxidative manner. Finally, the fat

content of hard MDM can vary dramatically, especially in chicken MDM. If MDM is purchased for the production of meat products, the specification of this raw material should state the bacteria count as well as the level of protein and fat.

No significant differences can be seen between the functionalities of chicken, beef or pork hard MDM when comparable levels of fat and protein are present within the raw material. However, hard MDM from pork or chicken demonstrates a significantly shorter shelf life, also under freezing conditions, than beef MDM. This is due to a significantly higher level of unsaturated fatty acids present in the fat fraction of chicken or pork MDM fat, than in beef fat, and rancidity develops quickly within such material.

Hard MDM contains between 12 and 15% protein and this figure depends heavily on the amount of fat present at the same time. The 12–15% protein represents around 60–70% of the protein found in muscle meat. However, the ability of hard MDM to immobilize added water, as well as emulsifying fat, cannot be based on the protein content in comparison with lean muscle meat, as a fair proportion of protein which is analytically present is damaged during the manufacture of the material and is not functional any longer. In addition, hard MDM is of fine and mushy consistency because of its manufacturing process and, as such, does not support a firm texture in the final product. Quite commonly, hard MDM shows a high pH value of around 6.2–6.4 and therefore has a strong negative impact on the development of the curing colour. Finely cut emulsified sausages, made out of MDM only, often exhibit a dark colour in the finished product as a result.

Most countries have guidelines in place for the production of hard MDM. Common guidelines are, for example, that bones to be processed for the production of hard MDM have to be stored at 0–2 °C no longer than 24 h or frozen for a maximum of 8 days prior to processing. Hard MDM has to be frozen straight after production (predominantly in blocks) or utilized within 24 h after production. Another guideline found is that freshly produced hard MDM can be utilized 48 h after production when salt and nitrite are added after production.

Soft MDM is obtained from meat trimmings, which are high in connective tissue and cartilage such as shank meat. These materials are put through a machine which separates meat from connective tissue based on the different degrees of firmness and textures of those materials. This process saves much labour and commonly, a 'Baader' machine is utilized. The meat material obtained from this separation process is high in protein and an excellent material for all types of sausage and coarse-minced salami.

The production of soft MDM takes place in the following stages. The material to be processed is commonly minced first with the 13–20 mm blade and subsequently fed into the 'Baader' machine. Lean meat, owing to its soft texture, passes through holes in a rotating barrel into the inside of the barrel and is discharged through the open side on the barrel. Connective tissue and ligaments are discharged in front of the machine and do not penetrate into the

inside of the barrel. This material is rich in connective tissue and can be perfectly utilized in cooked sausages as the high content of connective tissue, and therefore collagen, contributes very positively to the bite of a cooked sausage. Such collagen-rich material can also be applied in raw fermented salami (see Chapter 16, Section 16.1.1). Soft MDM contains around 15–17% protein, about 70–80% of the protein in lean muscle meat (around 21% protein). Therefore, the WBC and fat emulsification capacity of soft MDM is around 70–80% of that of lean muscle meat and all protein within soft MDM is still functional as it does not become damaged during processing.

### 4.3 Hot boning of meat: ‘warm-meat effect’

Years ago, when phosphates were not permitted in the manufacture of sausages in many countries, the WME was used predominantly for the production of cooked sausages. Nowadays, as the application of phosphates is an everyday occurrence, only specialized companies still practise this tradition.

In beef, it takes around 4–8 h after slaughter (bleeding) for around 60% of the glycogen present in muscle tissue at point of slaughter to be used up during post mortem glycolysis. At this point, the concentration of ATP within muscle tissue drops below 1  $\mu\text{mol}$  per gram of muscle tissue and the onset of rigor mortis takes place. When processing beef, 4 h after slaughter is commonly taken as the time after which actin and myosin are no longer preserved as separate fibres and rigor mortis starts to take place. At this point, actin and myosin remain bound together in the actomyosin complex as a result of having insufficient ATP left in the muscle to dissociate actin from myosin. Up to the point where actin and myosin are present as the actomyosin complex, solubility of the proteins is extremely high as permanent cross-links have not yet been established between actin and myosin. The point of non-separation of the fibres is reached in pork after around 2–4 h and, from the onset of rigor mortis onwards, the solubility of protein is significantly reduced as a result.

To preserve the high degree of solubility, or the WME, ‘hot’ beef carcasses are deboned and meat is minced with the 8–13 mm blade or cut in the cutter at a slow speed. Salt is added at a concentration between 1.5% and 5.0%. Increasing the ionic strength through the addition of salt into muscle tissue, in combination with a high pH value and high levels of ATP present in the warm meat prior to the onset of rigor mortis, causes a strong repelling effect between protein molecules. Thus, the gap between actin and myosin is enlarged and no cross-links can be formed between those two fibres. The gap between actin and myosin is simply too large and the cross-links from myosin towards actin are too short to connect, or bond, with actin.

The major difference between meat with the WME preserved (‘preserved’ meat) and meat which experiences a ‘normal’ rigor mortis without being deboned and salted is that, despite going through a complete rigor mortis,

no, or only a very small number of, cross-links between actin and myosin are formed in 'preserved' meat. This is the basis for the extremely high solubility of 'preserved' meat even though complete rigor mortis took place. An emulsion of lean 'preserved' meat can then be stored afterwards at 0–2 °C for 3–4 days and utilized for the production of cooked sausages and it can also be stored frozen for a period of 2–3 months. The addition of phosphates is not required when producing cooked sausages using 'preserved' meat given that there are no actomyosin complexes to be separated, which is the primary reason for the addition of phosphates in cooked sausages.

Preserving the WME in pork is in practice hardly possible because pork generally contains only a small amount of glycogen at the point of slaughter. Therefore, the period of time in which energy is rebuilt after slaughter is short and permanent cross-links between actin and myosin are obtained around 2–3 h after slaughter, with the slaughtering process itself lasting for around 40 min already. When preserving the WME in pork, the meat must usually be processed for a maximum of 1–2 h after slaughter (bleeding). It is virtually impossible to debone the hot carcass, to mince the meat (or to cut it in a cutter) and to add salt quickly enough for the protein to have sufficient time under the impact of salt to swell so that no cross-links are formed between actin and myosin. Another option is to inject the meat straight after slaughter with brine containing salt and then to debone and mince the injected meat afterwards. The advantage here is that salt is introduced as the very first step within the process and subsequent steps, such as deboning and mincing, takes place afterwards whilst salt is already working on protein and swelling is taking place. This process of injecting warm meat is occasionally applied within the production of cooked ham where cuts such as pork legs are injected straight after slaughter. Such a treatment results in around 4% more cooking yield and better flavour as well. Despite that, the process of injecting entire legs straight after slaughter is very rarely carried out as the subsequent steps, such as boning and trimming, are more difficult than handling raw chilled meats.

The WME effect can also be preserved by freezing warm meat before cross-links are formed between actin and myosin (see Section 4.4).

#### **4.4 Thaw rigor**

Meat is generally frozen once rigor mortis is completed but, if meat is frozen before glycolysis is completed and the level of ATP within muscle tissue is still more than 1  $\mu\text{mol}$  per gram of tissue, actin and myosin are not bound together at this stage to form the actomyosin complex. As mentioned above, the WME can be preserved by freezing warm meat before the onset of rigor mortis. In fast freezing, granulated warm meat is normally exposed to a cryogenic gas such as carbon dioxide ( $\text{CO}_2$ ) or nitrogen ( $\text{N}_2$ ). Warm meat can be cooled by the impact of nitrogen from 37 °C down to –15 °C in 4–5

min. By exposing warm meat to a cryogenic gas and fast freezing, glycolytic enzymes are inactivated and post-mortem glycolysis is inhibited.

Thaw rigor, or delayed rigor mortis, has to be avoided in meat used in the production of sausages, which has had the WME preserved through fast freezing. Therefore salt and water are applied during comminution in the bowl cutter before frozen meat is completely thawed. Otherwise, rigor mortis will take place very quickly in the bowl cutter once the meat is thawed and a large number of cross-links between actin and myosin will be formed during 'delayed' rigor mortis. The addition of salt and water to the cutter before the meat is fully thawed increases the gap between actin and myosin by creating repulsion forces. The myosin cannot bind to actin and rigor mortis takes place in the cutter without the formation of cross-links. If water and salt are not added, or they are added too late, the meat experiences very rapid and strong contractions and swelling of the fibre structure takes place too late as well.

When warm-frozen meat is used in products such as sausages, salt and water have to be added before the ice present within meat turns to water, to ensure that a gap is obtained between myosin and actin owing to swelling of the fibre structure. If meat is frozen soon after slaughter to preserve the WME before rigor mortis occurs, electrical stimulation (see Section 4.6) is a remedy in order to avoid serious contraction during thawing of warm meat as ATP is utilized during stimulation of the muscle and is not available afterwards to cause contraction. The WME is hardly used nowadays but, when it is, thaw rigor is avoided by adding salt and water to the bowl cutter at the right time during processing.

## 4.5 Cold shortening

Cold shortening is the result of cooling warm or hot carcass meat too quickly after slaughter. Cold shortening is predominantly seen in beef as well as lamb if the internal temperature of the meat reaches (or drops below) 14 °C, whilst the pH value is still around 6.0–6.2 at this stage during rigor mortis. A temperature of around 14 °C is normally achieved only after 12–16 h in cattle after slaughter and, in pork, a temperature below 15 °C should not be attained within 4–5 h after slaughter.

Another such temperature–pH relationship is that temperatures of below 7 °C within meat should not be attained whilst the pH value is still around 5.8–6.0. The combination of high pH value and low temperature present at the same time in muscle tissue damages the SPR and contraction, as well as relaxation, of the muscle fibres post mortem cannot be controlled properly any longer. When damaged in this way, the SPR does not reabsorb the  $\text{Ca}^{2+}$  ions released for contraction and a permanent high concentration of  $\text{Ca}^{2+}$  ions, together with the non-activation of the enzyme actin–myosin ATP-ase due to the damaged SPR, causes the muscle fibres to contract heavily. All

energy obtained in an anaerobic way post-slaughter is utilized for muscle contraction only and a large number of cross-links between actin and myosin are established. As a result, meat is always tough and the solubility of the protein is greatly reduced as well, as solubility correlates with the numbers of cross-links within muscle tissue.

Cold shortening does not occur at, or below, a pH value of 6.0 and, once such a pH value is obtained, the carcass can be chilled more rapidly but, as stated above, temperatures in muscle tissue below 7 °C at this point must be avoided. Another way to avoid cold shortening is the 10–10 rule, meaning that the temperature within meat on a carcass should not be below 10 °C within 10 h after slaughter. This rule of thumb applies to carcass meat with bone in. When meat is deboned in a hot stage of processing, the boneless meat should not be chilled below 16 °C within 10 h. The bone structure of carcass meat counteracts the contraction of the muscle fibres and, given that this counter-force is not in place by deboned meat, chilling of boneless meat has to take place at a slower rate.

Red muscles are more susceptible to cold shortening than white muscles because white muscles demonstrate a more sophisticated and developed SPR, which is responsible for the release of  $\text{Ca}^{2+}$  ions. The SPR of white meat can reabsorb  $\text{Ca}^{2+}$  ions more effectively than that of red meat and the impact from the damaged SPR in white meat is not as strong as in red meat. The release of  $\text{Ca}^{2+}$  ions post mortem in high amounts results in a strong stimulation of the fibres actin and myosin which subsequently leads to strong contraction. If those ions are not reabsorbed effectively, as takes place in red meat, toughness is the consequence.

Contrary to cold shortening, rigor shortening occurs when the carcass is cooled too slowly. The combination of a pH value of around 5.8–6.0 shortly before the onset of rigor mortis with high temperatures in muscle tissue above 22 °C causes severe shortening known as rigor shortening and, as a result, the muscle fibres can shorten by up to 25% of their original length. In extreme cases, when the temperature of the meat is around 30 °C at the mentioned pH levels, shortening of the fibres can be up to 45% of their original length. An associated problem with cooling carcasses too slowly is that a high temperature is found in the large, or thick, parts of meat for a prolonged period of time. Enzymes present in such warm areas become very active and decarboxylation (splitting away of a COOH group) occurs, which can give the meat a rusty-green colour as well as an unpleasant smell. During this process, large amounts of acetic and butyric acid as well as toxic biogenic amines are formed.

Cold shortening can be observed occasionally in pork and predominantly in such muscles where rapid chilling took place on an exposed muscle surface. In pork, a slight degree of cold shortening is sometimes desired in order to reduce the level of PSE meat (see Section 4.1) because a slight degree of cold shortening is less damaging economically than obtaining PSE meat.

Very fast chilling post-slaughter at temperatures of around  $-20^{\circ}\text{C}$  without electrical stimulation does not result in cold shortening but this technique is not widely applied yet. This could be because the application of such low temperatures, in conjunction with a high air speed, to the surface of the meat results in 'hardening', or even slightly frozen conditions, on the surface of meat. Despite the continuous impact of low temperatures, the degree of shortening is reduced, as the hardened fibres just do not contract severely any longer. The effect of gravity on the carcass is also significantly reduced when muscles are hardened. However, in general it is only possible to attain a temperature of around  $0^{\circ}\text{C}$  within 4–5 h after slaughter within thin pieces of meat while not dropping the temperature below  $-1.2^{\circ}\text{C}$  in order to avoid freezing. The important parameter for this technique to avoid cold shortening by very fast chilling is the use of thin pieces of meat and not whole carcasses, as meat (containing much water) generally is a very poor conductor of heat. It is almost impossible to lower the temperature within thick pieces of carcass meat to  $0^{\circ}\text{C}$  in the core quickly while avoiding freezing of the meat material on the surface as would be caused by dropping the temperature below  $-1.2^{\circ}\text{C}$ .

#### **4.6 Electrical stimulation**

The impact of cold shortening can be minimized, or avoided, by electrical stimulation, which speeds up post-mortem glycolysis. Electrical stimulation is widely applied to beef carcasses and electrical wires are attached to the extremities. A low-voltage treatment, around 15–70 V for around 30 s and 20–50 Hz is applied immediately after sticking (bleeding). Higher voltages such as 100–600 V can be applied up to 45 min post-slaughter once the slaughtering process is completed and the two skinless as well as degutted halves of the body have been obtained. The application of impulses lasts for around 25–30 s and the frequency of the electrical impulses is around 15 impulses per minute. Higher voltages are not used as they would cause the pH value to drop quickly and PSE-character beef (a low pH level in meat combined with high temperatures) could be obtained as well as rigor shortening (see Section 4.5). Up to 2500 V are applied for up to 1 min to sheep still in their skin and wool, as the skin, including the wool, is a poor conductor of electricity.

During electrical stimulation, energy present in muscle tissue in the form of glycogen, CP and subsequently ATP is utilized for contraction and relaxation of muscle fibres, controlled by SPR that has not been damaged. Post-mortem energy is not solely utilized for contraction, as happens during cold shortening, when contraction and relaxation are not controlled owing to a damaged SPR. Once the significant amount of energy present in the carcass meat post-slaughter is exhausted, the carcass can be cooled quickly and cold shortening will not take place, because there is insufficient ATP left, which could be used for the contraction of the muscle during subsequent chilling.

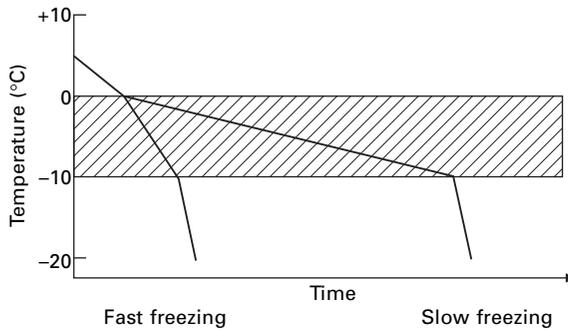
During electrical stimulation, the pH value within muscle tissue drops by between 0.2 and 0.6 pH units to a pH value of around 6.3, and rigor mortis overall is completed more quickly than it would be without electrical stimulation. The application of electrical stimulation causes an earlier onset of rigor mortis by around 3–4 h. Once the pH value in meat has dropped to around 6.0–6.2, fast chilling of the carcass can be applied and no cold shortening will take place. Electrical stimulation is rarely applied in pork owing to the risk of obtaining PSE-character meat if over-stimulated but is occasionally applied to poultry such as turkey.

#### 4.7 Freezing and thawing of meat

Worldwide, a huge amount of meat is handled and distributed in a frozen state as storage of meat over a prolonged period of time can only be achieved by freezing. Bacterial growth generally stops at around  $-12\text{ }^{\circ}\text{C}$  but bacteria are not killed at such temperatures and it is vital to understand that freezing does not improve the microbiological status of meat. Some strains of mould are known even to grow at temperatures as low as  $-14\text{ }^{\circ}\text{C}$  and below. Any meat or fat to be frozen should be packed or wrapped in some kind of foil or bag in order to avoid freezer burn (see Section 4.8). Packing of meat also avoids dehydration on the surface of the frozen material and acts as a form of protection against contamination during handling. Freezing is a highly energy-consuming process, and therefore in general it is deboned meat that is frozen, eliminating the cost of freezing bones. The conversion of  $0\text{ }^{\circ}\text{C}$  water to  $0\text{ }^{\circ}\text{C}$  ice requires the extraction of around 300 kJ of 'latent heat' per kilogram of water. In comparison, the cooling of water from  $30$  to  $0\text{ }^{\circ}\text{C}$  requires only around 100 kJ per kilogram of water. Nevertheless, certain cuts such as pork legs, or whole chicken, are commonly frozen without being deboned.

During freezing, cellular water is turned to ice by removal of energy from the water (Fig. 4.3). In the first stage of freezing, the decrease in temperature within chilled meat from  $4$  to  $0\text{ }^{\circ}\text{C}$  is quite fast. Reducing the temperature further from  $0$  to  $-10\text{ }^{\circ}\text{C}$  (shown shaded) takes a very long time and a large amount of latent energy must be removed in comparison with the previous step. As explained above, turning water to ice is a highly energy-consuming process, and in particular the change in phase from water to ice uses much energy. The subsequent step to reduce the temperature even further from  $-10$  to  $-18\text{ }^{\circ}\text{C}$  occurs again quite quickly once the majority of water is already present as ice.

The freezing point of water within muscle tissue is around  $-1.2\text{ }^{\circ}\text{C}$  owing to the natural presence of salt in meat, and this lowers the point at which water turns to ice. Even at temperatures as low as  $-18\text{ }^{\circ}\text{C}$ , not all water is frozen and around 1–1.5% remains as water within the cell. By  $-3\text{ }^{\circ}\text{C}$ ,



**Fig. 4.3** Temperature reduction during the freezing of meat.

around 40% of the total water in a cell remains as water and freezing of all water in meat requires a temperature of around  $-49^{\circ}\text{C}$ .

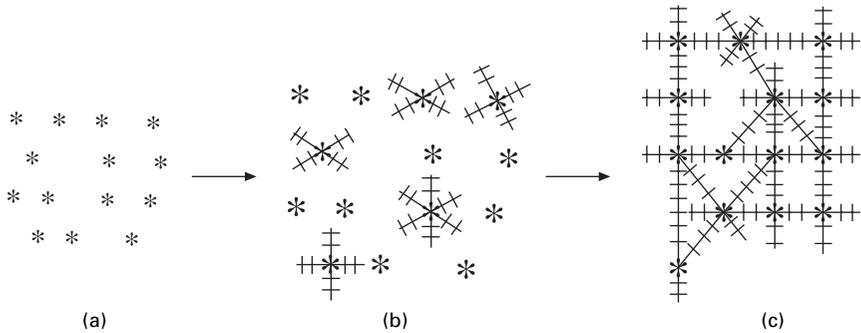
Different speeds of freezing are as follows.

- 1 Slow freezing, less than 0.5 cm/h.
- 2 Fast freezing, greater than 0.5 cm/h.
- 3 Very fast freezing, less than 10 cm/h (vegetables).
- 4 Ultra fast freezing, greater than 10 cm/h (tomatoes and cucumbers).

Freezing of meat or fat by exposing these materials to temperatures of between  $-18$  and  $-25^{\circ}\text{C}$  is a slow-freezing process, and meat is often frozen to temperatures within this range. Fast freezing using cryogenic gases such as  $\text{CO}_2$  or  $\text{N}_2$ , however, is regularly employed in the production of burgers or crumbed portioned food, such as chicken nuggets.

Large ice crystals are formed in the extracellular space during slow freezing, and these crystals grow further in size as water from the intra-cellular space is attracted to them. Water is frozen out of the extracellular space (i.e. it separates from other substances) and therefore the concentration of salt within the extracellular space increases. Because of the imbalance in salt concentration, water diffuses from the intracellular space towards the extracellular space in order to reach equilibrium and the cell is damaged chemically as the concentration of salt in the extracellular space increases. The cell is also damaged physically both by the water freezing out and by the low water content in the extracellular space. Finally, the large ice crystals formed damage the cell mechanically, by applying pressure to cell membranes. The crystallization of ice occurs in three steps. Firstly, tiny ice crystals are formed once water has turned to ice at a slow freezing speed (Fig. 4.4). Secondly, the tiny ice crystals increase in size as liquid water is attracted to ice crystals, Thirdly, a network of ice crystals, made from large ice crystals, is formed.

During fast freezing, a large number of very small ice crystals are obtained simultaneously within both the intracellular space and the extracellular space of the muscle cell. No water is frozen out of the extracellular space and therefore the concentration of salt and other substances in both the extracellular



**Fig. 4.4** Formation of ice crystals: (a) small isolated crystals; (b) larger cross-linked ice crystals; (c) large connected ice crystals.

space and the intracellular space remains in balance. Consequently, no, or very little, damage is done to the cell and cell membranes as no diffusion of salt takes place.

Several different methods of freezing are used in the meat industry. Plate freezers work on a semicontinuous basis and the material to be frozen is exposed to a large surface area on both sides. Plate freezers commonly operate with liquid ammonia and the temperature on the surfaces of the plate freezer is between  $-35$  and  $-40$  °C. Despite that, freezing using plate freezers is still categorized as slow freezing. Materials frozen by the help of plate freezers are generally of block or rectangular shape. Blast freezers operate by forced circulation of air and function at temperatures between  $-35$  and  $-40$  °C with an air speed of around 4–6 m/s. Generally speaking, blast freezers operate at between  $-20$  and  $-25$  °C but the high air speed reduces the temperature to the above-mentioned range around  $-35$  and  $-40$  °C, with blast freezing still being considered a slow-freezing process. On the other hand, fast freezing can occur when liquid  $N_2$  is applied, as  $N_2$  is an inert gas that boils at  $-196$  °C. During evaporation a large amount of energy is removed from the materials to be frozen, which causes the process of freezing to take place very quickly.  $CO_2$ , or dry ice, sublimates at a temperature of  $-78$  °C and fast freezing of materials is the result as well. Fast freezing by the application of cryogenic gases such as  $CO_2$  or  $N_2$  is the method commonly used to freeze a large selection of portioned food such as burgers, patties and nuggets. In general, all such portioned and frozen foods remain juicier after frying as a result of fast freezing.

The storage time of meat and fat materials under freezing conditions is largely determined by the amount of fat present within those materials as well as by the amount of unsaturated fatty acids within the fat itself. As a general rule, an increased fat content shortens storage time because rancidity develops at a faster rate within fat or fatty materials. Lean beef can be stored for around 1 year, lean veal for around 9 months, lean pork for around 6 months and pork fat for around 3–4 months at a temperature of between  $-18$  and  $-20$  °C. The difference between the storage times of lean beef and lean

pork arises because the fat within pork contains a significantly higher level of unsaturated fatty acids than beef fat and is therefore more susceptible to rancidity. Maintaining a constant temperature during storage under freezing conditions is vital to avoid any processes of diffusion or enzyme activity, which could lead to a greater degree of rancidity.

#### **4.7.1 Thawing of meat**

Thawing is the reverse process of freezing. The major difficulty when thawing is that the difference between the temperatures of the source of heat and the frozen meat cannot be too great for a prolonged period of time as this causes bacteria to grow at a fast rate, creating a microbiological risk.

Thawing takes place at a slower rate than freezing as water displays less thermal conductivity than ice. During freezing, the layer of ice formed on the outside of the material to be frozen removes energy quickly from the water still present within the inner layers of the material and, as a result, the water turns fairly quickly into ice.

During thawing, however, water is present first on the surface on the outer layers of the material to be defrosted. As water is a poor conductor of heat, the heat penetrates very slowly through the layer of surface water first before finally reaching the ice in the inner layers and core. This is why thawing takes place at a slower rate than freezing and also why a long period of time is required to thaw large pieces of meat fully; a large amount of water is already present in most areas of a large piece of meat, but water in the core remains as ice for a long time as the surrounding water acts as a barrier against heat.

The speed of thawing depends mainly on the speed of freezing in the first place.

##### *Frozen slowly; defrosted quickly*

Large ice crystals formed in the extracellular space during slow freezing turn into large water molecules during fast thawing and very little time is available for the water to penetrate from the extracellular space into the intracellular space when thawing at high temperatures. Only a small amount of water is absorbed from the intracellular space. By no means all the water in the extracellular space, which originates from thawing of the large ice crystals, can be absorbed, and this leads to high levels of thawing loss. Depending on the temperature applied during the thawing process, a loss of between 8% and 15% is common. The general rule when thawing slow frozen meat is that increased temperature applied during the thawing process leads to higher thawing losses.

##### *Frozen slowly; defrosted slowly*

When slow-frozen meat is thawed slowly, there is significantly more time during the thawing process for the intracellular space to absorb the large

water molecules produced in the extracellular space once large ice crystals thaw. The degree of thawing loss is significantly reduced compared with meat frozen slowly but thawed quickly. The major disadvantage of thawing slowly is the time and space required in order to thaw large quantities of meat fully on a regular basis.

*Frozen quickly; defrosted quickly*

Thawing quickly creates a large quantity of small water molecules from the many small ice crystals formed during fast freezing. During fast freezing, little damage will have been done to the cell, and the small water molecules obtained during fast thawing can be easily absorbed from the non-damaged cell into the extracellular space and intracellular space. Frozen ready-to-eat meals are an example of a product which is frozen quickly and then defrosted quickly, often by placing in a roasting oven or microwave and heating straight away.

*Frozen quickly; defrosted slowly*

Slow thawing of fast-frozen meats leads to the formation of large ice crystals from many small ice crystals shortly before ice is transformed back into water. As a result, serious damage is done by such large ice crystals to the muscle cells and large water molecules, obtained in the intracellular space and extracellular space, cannot be absorbed well. Significant thawing loss will be the result.

During the frozen state, the water activities  $A_w$  within the extracellular space and intracellular space in a cell are more or less the same. Once meat is being defrosted, the  $A_w$  in the outer layers, where ice first turns back into water, is higher than that in the still-frozen inner sections of meat. Based on that, water from the outer layers diffuses towards the still-frozen inner areas and water is subsequently reabsorbed in the thawed inner areas. The difference between the  $A_w$  values of the extracellular space and the intracellular space ultimately determines the amount of drip loss and an increased difference causes greater drip loss. Water, which cannot be absorbed properly by the cell, is collected in the extracellular space and is finally lost as drip. In summary, slow-frozen materials should be thawed slowly whilst fast-frozen materials should be thawed quickly.

When meat is thawed in water, then running water should be used because non-moving and non-renewed water provides a perfect breeding ground for all types of bacteria. Thawing meat in water presents an enhanced level of moisture on the outer layers of meat and as such supports bacteria growth. Water-soluble proteins are also washed out during the process. The loss in weight by thawing under running water is around 8–12% and several countries have regulations in place for microbiological reasons, to ensure that running water is used when thawing in water. Thawing of meat using running water requires much water and most companies have to pay for water twice, once as it comes into the factory and then once again for the amount of water

entering the drainage system. Therefore, thawing of meat in running water can become a very costly exercise, not to mention the disadvantages of the microbiological risk and the washing out of water-soluble proteins.

Meat can also be thawed in water by adding around 1% salt as well as 0.2% phosphate to the thawing water. This thawing process does not fall into the category of 'thawing with water' owing to the addition of some additives, and no running water has to be utilized, which is an economical benefit. Within such a process the water, or better called the 'thawing solution', is kept at a temperature of around 4–6 °C and meat thaws out quite quickly under those circumstances. Air is frequently introduced into the thawing tanks and the air bubbles create a slight tumbling effect which reduces thawing loss once more. The thawing loss is significantly reduced owing to the presence of salt and phosphates compared with thawing under running water and a loss in the vicinity of 2–4% is the norm. Another benefit is that, once meat is thawed, it demonstrates a temperature of around 4 °C, which is perfect for further treatment.

Thawing under vacuum is very efficient as the saturation temperature of steam under vacuum is around 18 °C and the transfer of heat to the material to be defrosted takes place in a very effective manner. This method of thawing regularly results in a gain in weight of around 1–2%, which is an unusual gain during this step of processing. Specially designed vacuum-thawing tumblers are available and steam is injected into the tumbler in regular intervals.

The utilization of microwaves for the purpose of thawing (or more specifically tempering) raises the internal temperature from around –20 to –3 °C very quickly (within 3–4 min) with basically no loss in weight. Microwaves cause agitation and friction among dipolar molecules of water when water-containing material (such as meat) is placed in an electromagnetic field, thus increasing the temperature quickly. The major problem currently in using microwaves to thaw meat is that raising the temperature from –3 °C to around 0 °C, the point where meat could be utilized for injection, takes a long time. This is due to the change in phases; intracellular water, still present as ice, has to be converted back into water. During this prolonged period of time, water droplets present on the surface of meat act like a magnifying glass under the continuous impact of microwaves, thus 'cooking' the meat on the surface which is not desired. As meat cannot be fully thawed on a large scale at this stage using microwaves, 'tempering' of meat is the term commonly used to describe the results of applying microwaves, as thawing would imply that the ice is turned completely back into water.

Much research is currently being carried out to find ways of raising the temperature of whole muscle meat from –3 °C to around 0 °C quickly, in other words to find easier ways of getting meat to a temperature suitable for processes such as injection. For the manufacture of products such as fresh and cooked sausages and burgers, however, it is not necessary to raise the temperature of meat and fat materials used in these products from –3 to 0 °C

as materials at  $-3\text{ }^{\circ}\text{C}$  can be further processed without difficulties and no thawing loss obtained.

Thawing with high-speed air is another way of defrosting meat in a cost-effective manner. Temperature probes are inserted into the core of the frozen meat (with a drill) as well as other spots within the meat to be defrosted. Steam is injected into the thawing room and rapidly cooled again. This cycle of steam injection and rapid cooling afterwards is repeated numerous times and is adjusted to the size of the block of meat to be defrosted and the thickness of the piece or block of meat determines the thawing programme to be applied. Thawing loss by applying this method is around 4–5% only compared with around 8–15% by thawing under running water and meat is fully thawed once the thawing cycle is completed without any semifrozen areas left inside. Hence, the thawed material exhibits a temperature between 0 and  $4\text{ }^{\circ}\text{C}$ , which is perfect for further processing such as injection.

Quite often, frozen meat seems to be of a darker colour than fresh chilled meat even though the concentration of myoglobin is comparable. On the other hand, fast-frozen meat can appear lighter in colour because of the way in which the large number of small ice crystals reflects light.

## 4.8 Freezer burning

Freezer burning on frozen meat occurs if meat is stored unpacked under freezing conditions. Because of the circulation of air in a freezer, ice present in the outer layers of frozen meat sublimates to gas. Sublimation is a process where water turns from its solid state (ice) into its gas-like state without ever being present in its liquid state (water). As a result of sublimation, the macromolecules within the outer layers of frozen meat change their configuration and proteins are denatured during the process. Following sublimation, less functional, or native, protein is available during processing and the head of the myosin molecule is predominantly denatured, although other parts of the myosin molecule, as well as actin, do not seem to be affected much at all. Denaturation of proteins is also the result of a high concentration of salt within the outer layers, because the level of moisture is low in comparison with the salt present naturally in meat. The combination of a low  $A_w$ , in conjunction with an increased level of salt, partly denatures protein.

Meat suffering from freezer burning exhibits on its outside layers a dry and fibrous structure owing to severe dehydration. Changes in colour within those layers can be observed as well and the original red colour changes into a lighter, sometimes even slight yellow–green, colour. Rancidity is also speeded up in those dry outside layers as a reduced water content favours the development of rancidity.

Freezer burning can be largely avoided if meat is frozen in a packed form. When packaged, water cannot sublime and moisture is not lost when ice turns into gas (sublimation) owing to air circulation in the freezer. If the

product is packed or covered properly, the packaging material does not allow the gas to evaporate. The packaging material should be of low water permeability and as little space as possible should be present between meat and the packaging material owing to possible oxidation in those areas.

## 4.9 pH value

The abbreviation pH stands for the Latin term *potentia hydrogeni* or 'potential of hydrogen' (effectiveness of hydrogen). The pH value has a significant impact on colour, shelf life, taste, microbiological stability, yield and texture of meat and meat products and is therefore one of the most important parameters within the production of meat products and meat itself. Quite often, the pH value is referred to as the 'acidity of meat', which is only partly correct as the pH scale ranges from 0 to 14 and covers not only the sour range (Fig. 4.5). The pH values of meat and meat products lie generally between 4.6 (raw fermented salami) and 6.4. At a pH value of around 6.4, meat is spoiled owing to enzyme activity, which produces a large amount of metabolic by-products as well as ammonia. Sliminess, bad smell and discolouration can be seen at this point as well.

A pH value of 0.1 is extremely sour, 7 is neutral whilst 14 is extremely alkaline.  $\text{pH} > 7$  corresponds to an alkaline solution,  $\text{pH} = 7$  to a neutral solution and  $\text{pH} < 7$  to an acid solution.

Mathematically, the pH value is the negative logarithm to the base 10 of the hydrogen-ion concentration  $[\text{H}^+]$  ( $-\log_{10} [\text{H}^+]$ ). The pH value expresses the concentration  $[\text{H}^+]$  in molarity, or moles per litre, but not in percentages. A change of 1 pH unit indicates a tenfold change in the concentration of hydrogen ions. The increments of pH are logarithmic, and not linear. A shift in pH value from 6 to 5 represents 90 units of hydrogen-ion activity, and a shift from 5 to 4 represents 900 units.

In a neutral solution, the hydrogen-ion concentration  $[\text{H}^+]$  and the hydroxide-ion concentration  $[\text{OH}^-]$  are equal, or of the same value. For example, if the concentration is  $10^{-7}$  mol  $\text{H}^+/\text{l}$  (or 0.0000001 mol  $\text{H}^+/\text{l}$ ), taking the negative logarithm of this concentration  $[\text{H}^+](10^{-7})$ , the number 7 is obtained. Therefore,

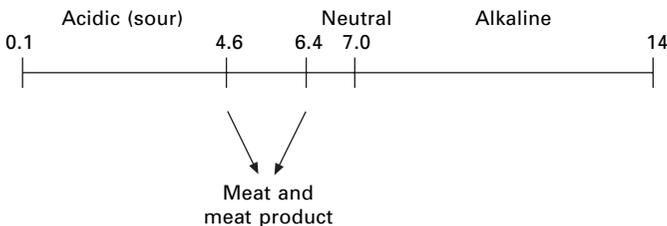


Fig. 4.5 pH scale.

the pH value of this particular solution is 7, which is neutral and this particular example represents the concentration  $[H^+]$  in pure water at 25 °C.

If the concentration  $[H^+]$  is 0.00001 mol  $H^+$  per litre of water within meat, or  $10^{-5}$ , the pH value of such a solution is 5, and therefore acidic. On the other hand, if the concentration  $[H^+]$  is 0.01 mol  $H^+/l$ , or  $10^{-2}$ , the pH value would be 2, which is very sour. The basic principle behind this is that a lower exponent results in a higher degree of acidity and a tenfold increase in  $[H^+]$  corresponds to a decrease of 1.0 pH unit. Because of the logarithmic nature and because it is based on the amount of  $H^+$  ions present, the pH value decreases if the concentration of  $H^+$  ions increases.

#### 4.10 $A_w$ value (water activity)

The water activity  $A_w$  is the ratio of the vapour pressure above a solution to the vapour pressure of pure water at the same temperature. In physical terms,  $A_w$  can be calculated in the following way:

$$A_w = \frac{P}{P_0}$$

$P$  is the vapour pressure of food at a certain temperature in degrees Celsius and  $P_0$  is the vapour pressure of pure water at the same temperature in degrees Celsius.

Another (simple) way of expressing  $A_w$  is the relative humidity (RH) of food divided by 100 (e.g. 98.5/100 results in  $A_w = 0.985$ ).

It is often a point of confusion that the  $A_w$  value in meat or meat products is not the total water content but rather the amount of free unbound water within the product in relation to its total water. To be more specific, pure water without any impurities and with no minerals in it demonstrates an  $A_w$  of 1.00 and, when discussing  $A_w$  value, at least two figures after the decimal point have to be used. By an  $A_w$  of 1.00 all water is unbound ('free') and available for bacteria as a source of food. Fresh meat exhibits an  $A_w$  of around 0.98, meaning that around 98% of the total water within meat is unbound whilst, at an  $A_w$  of 0.80, significantly less free water is present in meat. Air-dried cured meat products commonly display  $A_w$  of around 0.90–0.82 whilst spreadable raw sausage frequently shows an  $A_w$  of 0.94. Hungarian salami normally exhibits an  $A_w$  of around 0.83–0.85 and the  $A_w$  is largely determined for dried meat products by the degree of drying itself as well as the concentration of  $A_w$ -reducing substances such as salt and sugar. On the other hand, cooked sausages, as well as cooked ham, regularly exhibit  $A_w$  values of around 0.97–0.98 because more or less water is added to the product during processing.

Well-dried salami, after losing around 30% in weight during fermentation and drying, exhibits an  $A_w$  of 0.90–0.88. Despite the fact that an  $A_w$  of 0.90

still seems quite high, at such levels raw fermented salami is shelf stable without refrigeration because harmful microorganisms such as *Staphylococcus aureus* and *Salmonella* spp. do not produce toxin any longer at those  $A_w$  values (see Chapter 38). This simple example highlights why two figures after the decimal point have to be used because, by going from an  $A_w$  of only 1.00 (free water) or 0.98 (fresh meat) down to 0.90 (shelf-stable salami), dramatic changes in the physical behaviour, appearance and shelf life of a product can be seen. The  $A_w$  value in meat products can be reduced by the impact of drying (removal of water), the addition of sugar or salt to food (binding of water through ions), the addition of fat (less water added to the meat product) or freezing (immobilization of water).

#### 4.11 $E_h$ value (redox potential)

Redox (reduction–oxidation) reactions (Fig. 4.6) are one of the most commonly occurring reactions in cells and are mostly catalysed by enzymes. Reduction and oxidation refer to the exchange of electrons from a donor on to an acceptor where the donor is oxidized and the acceptor is reduced at the same time. A molecule taking up (gaining) electrons is the oxidizing agent (oxidant) and, by gaining an electron, the oxidizing agent is reduced. The reducing agent (reductant) gives away, or donates, electrons and is oxidized as a result. The process of oxidation is a release, or removal, of electrons whilst the process of reduction is a gain, or addition, of electrons. According to the law of electroneutrality, the oxidation of one substance always corresponds to the reduction of another substance. An oxidizing agent changes via a reduction (gain of electrons) to a reducing agent. A reducing agent turns via an oxidation (donation of electrons) into an oxidizing agent.

The most well-known example for such a redox reaction couple is the reaction of  $\text{Fe}^{2+}$  with oxygen ( $\text{O}_2$ ) in the haemoglobin system:



In this example, doubly positively charged iron is oxidized by the impact of  $\text{O}_2$ . Since  $\text{Fe}^{2+}$  gives away an electron to  $\text{O}_2$ , it is a process of oxidation.  $\text{O}_2$ , taking up the electron, is the oxidizing agent whilst  $\text{Fe}^{2+}$  is the reducing agent owing to the donation, or giving away, of an electron.

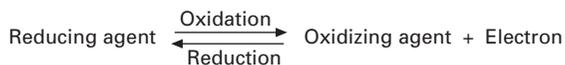


Fig. 4.6 Oxidation–reduction.

Both substances act as the redox couple and such oxidation–reduction reactions cause the exchange of free energy. The flow of electrons in the exchange of free energy can be measured and is called the redox potential or electromotive force, a measurement for oxidizing or reducing substances expressing the ability of absorbing or donating electrons (electron affinity) within food. The redox value is expressed in millivolts and is the amount of energy gained by transferring 1 mol of electrons from an oxidant to  $H_2$ .

The  $E_h$  value depends largely on the chemical composition and the  $O_2$  pressure within food as well as the pH value. A reduced  $E_h$  value lowers the ability for aerobic bacteria to grow whilst a high  $E_h$  value reduces the growth of anaerobic bacteria. A decrease in the  $E_h$  value can be achieved by the addition of reducing agents such as ascorbic acid or erythorbate or the application of vacuum during the manufacture of a product.

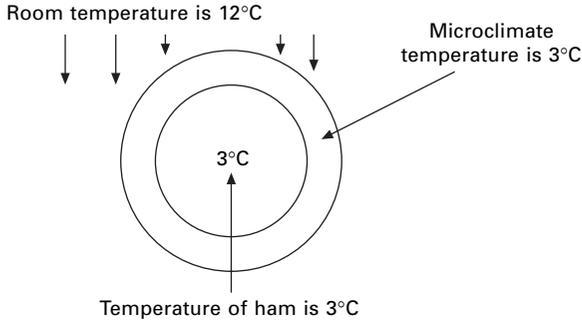
## 4.12 Condensation water

Air can hold (bind) moisture according to its temperature and warmer air can hold more moisture compared to cold air. The term ‘relative humidity’ (RH) refers to the actual level of moisture in the air compared with the moisture content of saturated air at the same temperature. There is a substantial difference between the amount of moisture in air with 75% RH at 4 °C and in air with 75% RH at 15 °C. The amount of moisture in the air at 4 °C air is significantly less than that in air at 15 °C.

Formation of condensation water on meat and meat products is frequently neglected and leads to microbiological spoilage, discolouration and a significantly shorter shelf life. Condensation water is formed on the surface of a cold material if such cold materials are exposed to a much warmer environment. When the cold material comes into contact with the warmer environment, the dew point is exceeded and the amount of moisture that cannot be bound by the air surrounding the cold material can be seen as free water on the surface of the cold material.

A cooked ham to be sliced and packed, for example, coming out from the chiller (refrigerator), exhibits a surface temperature of 3 °C and the temperature in the slicing room is 12 °C (Fig. 4.7). A cold microclimate surrounding the cold ham forms and the temperature within this microclimate is more or less the same as the ham itself, 3 °C. The ability of this microclimate (3 °C) to hold moisture is significantly less than the ability of the significantly warmer air present in the slicing room (12 °C). As a result, the amount of moisture that cannot be bound by the air within the cold microclimate ‘falls out’ as the dew point is exceeded and can be seen as free water on the surface of the ham. This condensation water is, as stated, free unbound water and it is fully accessible for all microbes to use as food.

As shown in Table 4.2, in order not to exceed the dew point and therefore not to obtain condensation water on the surface of the product the maximum



**Fig. 4.7** Formation of condensation water.

room temperature in this case would be 7.2 °C if the room has an RH of 75%. To avoid the formation of condensation water on meat and meat products, the following action can be taken.

- 1 Reducing the temperature in the room, where meat or meat products are placed, in order not to exceed the dew point based on the difference between the surface temperature of the product and the air temperature within the room.
- 2 Reducing the RH in the room by not changing the temperature in the room.

Table 4.2 shows the maximum temperature in the slicing or packaging room in degrees Celsius in relation to the temperature of the meat or meat products in order to avoid formation of condensation water at a certain level of RH in the room.

**Table 4.2** Temperatures of the meat product and room temperatures at various levels of RH

Surface temperature of meat product (°C)	Maximum temperature (∞) in the room at the following RHs			
	60%	65%	70%	75%
0	7.5	6.5	5	4
1	8.4	7.6	6	5
2	9.5	8.5	7	6
3	10.4	9.5	8	7.2
4	11.8	10.6	9.5	8.5
5*	13.0	11.5	10.4	9.7
6*	14.1	12.7	11.5	10.4
7*	15.5	13.8	12.4	11.4
8*	16.4	14.9	13.7	12.7

\*Temperature that should never be present for meat or meat product at all. They are cited only for the purpose of completing the table.

### 4.13 Maillard reaction

The Maillard reaction, named after L. C. Maillard, is also known as non-enzymatic browning. It is an extremely complex process and is the reaction between reducing sugars and proteins by the impact of heat. The Maillard reaction starts with the reaction of a reducing sugar with an amine, creating glycosylamine. These substances undergo a reaction called Amadori rearrangement to produce a derivate of amino deoxy fructose. The reaction is continuous and very reactive intermediate substances are formed which subsequently react in several different ways. Eventually, a furan derivate is gained and this derivate reacts with other components to polymerize into a dark-coloured insoluble material containing nitrogen. The Maillard reaction also takes place at room temperature but at a much slower rate and occurs at its slowest at low temperatures, low pH and low  $A_w$  levels.

Excellent examples of the Maillard reaction are the crust of roast pork or baked bread. The Maillard reaction also creates, besides colour, countless complex flavours at the same time. The sulphur-containing amino acids methionine and cysteine play a primary role within the formation of the flavour-intensive components gained during the Maillard reaction. The flavour of such roasted or grilled meats also contains heterocyclic compounds derived from amino acids, nucleotides and sugars from the Maillard reaction such as oxopropanol and hydroxymethylfurfural. Unsaturated fatty acids, as well as aldehyde–fatty–acid components, also contribute to the formation of odorous heterocyclic flavour compounds during the Maillard reaction.

### 4.14 Caramelization

Contrary to the Maillard reaction, caramelization is a reaction between two sugars (no protein is involved) via the impact of heat. It is the thermal degradation of sugars resulting in volatiles, caramel aromas and brown-coloured caramel colours. Caramelization requires temperatures above 120 °C to take place and it happens within a pH range 3–9. Different types of sugar, mainly monosaccharides, undergo intramolecular changes via the impact of heat. The first step in the process is an enolization, which causes the formation of aliphatic sugar degradation products. Those substances react further to give heterocyclic and carbocyclic compounds via a condensation reaction. In several steps afterwards, intermediate products such as osuloses are obtained. Osuloses are dicarbonyl compounds such as deoxyhexosulose and are responsible for the formation of the caramel colour as well as the sweet and mellow volatile caramel flavour. The browning process itself takes place at a much faster rate at higher temperatures. Onions contain high level of sugars and, during frying of onions, the colour changes through caramelization, leading to the typical mellow and sweet flavour. Onions also

contain tiny amounts of protein and the browning of fried onions is also partly caused by the Maillard reaction.

#### 4.15 Conductivity of meat

The conductivity of meat describes the amount of electric current flowing through meat within a specified amount of time. The result is expressed in millisiemens per centimetre. Measuring the conductivity in pork meat is used to determine its technological quality several hours post-slaughter. The conductivity can be measured in pork around 1 h after slaughter to detect PSE meat but is not as reliable as measuring the pH value for the same purpose, as the values obtained from non-PSE meat in comparison with those from PSE meat at this early stage post-slaughter are too similar. Only extremely high values 1 h post-slaughter, above 14 mS/cm, indicate that PSE meat is obtained. Measuring the conductivity between 4 and 24 h post-slaughter in pork in the loin muscle (*Musculus longissimus dorsi*) gives a reliable result for PSE whereas measuring the pH value after such a period of time is no longer reliable in the detection of PSE meat. Measuring the conductivity 24 h post-slaughter in pork should result in a maximum value of 7–8 mS/cm. Values above 8 mS/cm obtained 24 h post-slaughter indicate PSE meat and such measurement, even 24 h post-slaughter, allows the reliable detection of PSE meat. Meat showing PSE character exhibits damaged cell membranes to a greater extent as a result of partial denaturation (see Section 4.1), which results in higher conductivity values as fluids between the intracellular and intercellular spaces are exchanged to a higher degree as well. Simply expressed, the conductivity reflects the intactness of the muscle cell and therefore its WHC. Higher values express greater cell damage and therefore a lower WHC. The type of chilling applied to carcasses of pigs has an impact on conductivity; meat on carcasses exposed to shock chilling for around 1–2 h at around  $-10^{\circ}\text{C}$  before being chilled further to around  $1-3^{\circ}\text{C}$  demonstrates lower conductivity values and therefore less cell damage than meat on carcasses which are chilled to only  $1-3^{\circ}\text{C}$  post-slaughter. These phenomena are very similar to the development of PSE meat as faster chilling of a pig carcass during the first 1–2 h post-slaughter reduces the likelihood of the development of PSE meat and as such improves the WHC of the meat itself.

## 5

### **Additives: phosphates, salts (sodium chloride and potassium chloride, citrate, lactate) and hydrocolloids**

Additives are materials applied during the manufacture of food in order to increase, restore or enhance attributes such as taste, colour, texture, firmness and shelf life. Although the ‘dangers’ of food additives are commented upon almost daily in the media, food additives are in fact among the most researched substances in the world. Before an additive is permitted for use in meat products, it must fulfil three conditions.

- 1 It must be necessary for product quality (technologically needed)
- 2 It must not be a threat to the human health.
- 3 It must not mislead the consumer.

Most countries today try to limit the number of additives permitted in meat products. In a situation where there are, for example, five permitted ‘emulsifiers’, an additional sixth would probably not be authorized unless there was a serious technological need. In a case where there is a need for a ‘new’ additive, another problem is to prove that consumption of this additive over a certain period of time (mostly years) at a certain level does not have any negative impact on human health. This prerequisite is commonly fulfilled by conducting long-term studies based on a certain available-daily-intake level. The additive must also not disguise a quality defect in a food, caused by poor manufacturing practice, or hide a microbiological risk. An additive to improve the appearance of discoloured meat, for example, would not be permitted.

## 5.1 Phosphates

Phosphates are the salts of phosphoric acid and are widely applied in the meat industry. These salts are made out of positively charged metal ions and negatively charged phosphate ions, which are derived from the corresponding acid by loss of  $H^+$ . For example, sodium tripolyphosphate (STPP) dissolves in solution into  $Na^+$  ions and the negatively charged  $PO_4^-$  ion which originates from the phosphoric acid.

### 5.1.1 Production of phosphates

Phosphates can be made in several ways but the most common way is as follows.

- 1 Phosphoric acid is obtained from raw or rock phosphorus, commonly with the help of other chemicals.
- 2 The phosphoric acid is cleaned in several stages to obtain food-grade phosphoric acid.
- 3 The food-grade acid is neutralized by mixing with a strong alkali. Monophosphates (salts) are obtained as a result of a reaction between the strong acid and alkali, and water is removed during the process. Monophosphates have one phosphorus atom within the molecule.

The next steps involve the manufacture of higher-polymer phosphates, which takes place via a condensation reaction at temperatures around 600–800 °C by melting individual monophosphates together to form diphosphates, also known as pyrophosphates. Pyrophosphates contain two phosphorus atoms in the molecule. Once another monophosphate is added on, tripolyphosphate is obtained and so forth. Within such a condensation reaction, polyphosphates with up to 1000 phosphorus atoms in the molecule can be produced.

### 5.1.2 Properties of different phosphates

There are three basic forms of phosphate.

- 1 Ring phosphates.
- 2 Chain phosphates (linear phosphates).
- 3 Combinations of ring and chain phosphates.

In most countries, only chain phosphates (linear) are permitted to be applied in the meat-processing industry and also in the treatment of seafood. The heavily used term ‘hexametaphosphate’ originates from American English and is not fully correct. Sodium hexametaphosphates is the only correct term for chain phosphates; metaphosphates are normally trimetaphosphates or tetrametaphosphates, which are ring shaped and, as such, are not permitted in meat processing. Sodium hexametaphosphates commonly exhibit a  $P_2O_2$  content (see Section 5.1.3) of 60–70.

Phosphates fulfil several functions in meat products.

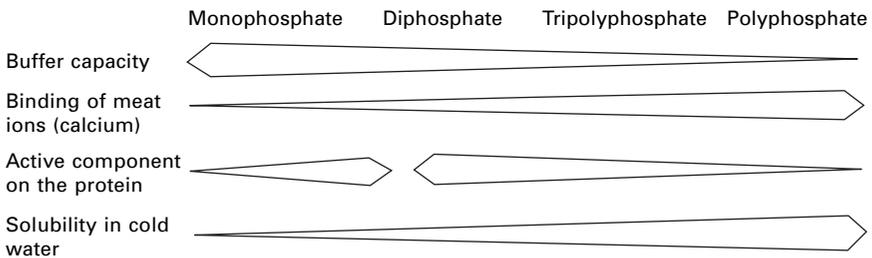
- 1 They 'neutralize' the cross-link between actin and myosin, formed during rigor mortis, and support the dissociation of the actomyosin complex into separate fibres again. Phosphates loosen the electrostatic forces within the actomyosin complex; this function of phosphates is known as the 'specific effect' on the muscular protein, as it contributes greatly to the solubility of muscular protein. Only phosphates are able to separate actin and myosin after rigor mortis and that is the primary reason for the worldwide use of phosphates. The separation of actin and myosin takes place as a result of the binding of the negatively charged phosphate ions with the positively charged  $Mg^{2+}$  or  $Ca^{2+}$  ions. The positively charged  $Mg^{2+}$  and  $Ca^{2+}$  ions play a vital role in muscle contraction as well as relaxation and are present at the point where binding between actin and myosin occurs by myosin locking into actin.
- 2 Through the addition of salt as well as phosphates at the same time to a meat product, the muscular protein becomes soluble and solubilized, or activated. The protein can then immobilize high levels of added water as well as emulsify a large amount of fat, given that activated meat protein is an excellent emulsifier of fat.
- 3 Nearly all phosphates, as well as blends of phosphates, utilized in the meat-processing industry, are alkaline phosphates and the addition of alkaline phosphates to slightly sour meat leads to a rise in pH inside the meat product. A movement further away from the IEP takes place and enhanced WBC of the protein is the result because greater electrostatic repulsive forces create larger gaps between actin and myosin and larger amounts of added water can be bound.
- 4 The addition of phosphate, which is a salt itself, increases the ionic strength of the meat and an increased ionic strength leads to a more severe degree of swelling from the muscle fibres and activation of protein. Enhanced levels of activated and swollen protein support the immobilization of added water to meat products and the emulsification of fat.
- 5 Phosphates are slightly bacteriostatic and growth of bacteria is marginally slowed down. This slowing of growth, however, is almost negligible in meat products as the concentration of phosphates required to show a significant impact regarding bacterial growth would be greatly above the permitted level.
- 6 Phosphates can chelate (bind) heavy-metal ions and therefore slow down the process of rancidity as heavy-metal ions are pro-oxidative materials.
- 7 Phosphates are occasionally applied in salami because they make the mass 'fill better'. The sausage mass comes out of the filling pipe with less smearing, which is subsequently positive regarding drying of the product.

In meat-related applications, blends of different phosphates are commonly introduced as such blends are usually tailor made for a specific application and perform significantly better than a single type of phosphate.

Some important issues in choosing the correct phosphate blend are as follows (Fig. 5.1).

- 1 Solubility must be considered. When preparing a ham brine using ice-cold water, the phosphates must still dissolve quickly and completely. Longer-chained polyphosphates demonstrate significantly better solubility in cold water than short-chained phosphates (pyrophosphates) do.
- 2 A phosphate blend utilized for emulsified sausages (hot dog), contains predominantly short-chained phosphates because those phosphates act on the protein right away, as required in such an application. The component most active on the muscular protein is the short-chained pyrophosphate (diphosphate).
- 3 Monophosphates exhibit good buffer capacity, which helps to stabilize the pH value in a finished product over a prolonged period but have no effect on the muscular protein itself.
- 4 Pyrophosphates and tripolyphosphates are the preferred phosphates regarding emulsification of fat, as large quantities of protein are activated by the impact of these phosphates and activated protein is an excellent fat emulsifier.
- 5 Most phosphates are available as a sodium or potassium version and, in general, potassium phosphates exhibit better solubility than sodium phosphates.
- 6 Hence, granulated phosphates demonstrate better solubility in cold water than powdered phosphates do.
- 7 Different individual phosphates show significantly different pH values, and the pH value of a phosphate blend has to suit the application. Generally, phosphate blends for emulsified sausages exhibit a pH value between 7.0 and 8.3, while phosphates for ham brines exhibit a pH value around 9.0–9.3.

All large phosphate producers offer a wide range of phosphate blends for every possible application. There is a strong synergistic effect between salt

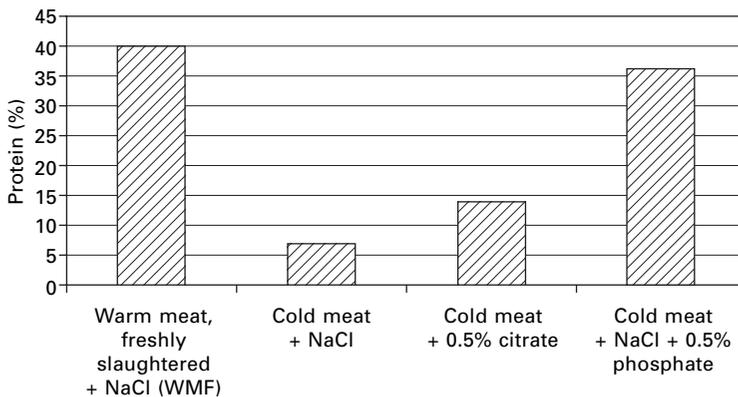


**Fig. 5.1** Properties of different phosphates.

and phosphates in regard to the activation of post-rigor meat protein. Phosphates themselves do not activate much protein at all but their function is to remove the links from the actomyosin complex. Once the links are removed, the addition of salt and water causes the protein fibres to swell, and activated, or solubilized, protein is ultimately obtained (Fig. 5.2).

Blends of phosphates used in emulsified products such as frankfurters and hot dogs as well as in burgers, patties and nuggets contain predominantly short-chained phosphates and no, or very few, longer- and long-chained phosphates are applied. In these products, phosphates together with salt have to act on the protein quickly, because the period of time to activate protein and then for the activated protein to 'cover' fat and hold water is very short. Short-chained phosphates, such as pyrophosphates, have a suitable high action speed for these applications and their poor solubility in water can be ignored as a large amount of mechanical energy is introduced into the product during manufacture. This high level of energy originates from cutting in a bowl cutter, shearing forces during cutting or mixing and emulsifying by passing the mass through an emulsifier. Experience shows that phosphate blends, which contain predominantly short-chained phosphates and exhibit a pH value of 7.0–7.5, produce a very firm emulsion in finely comminuted sausages, and such blends are best applied by working with a bowl cutter.

Specialized longer-chained phosphates are occasionally introduced into blends of phosphates for emulsion-type products and the emulsion becomes more elastic and soft as a result. Such soft emulsions are well suited to pumping processes using a mixer–emulsifier system where the finished emulsion is pumped to several filling stations. The longer-chained phosphates also help to increase the emulsification of fat and are present in phosphate blends for recipes which use a low meat content and at the same time high levels of fat and water. This type of phosphate blend frequently has a pH value of around 8.5.



**Fig. 5.2** Protein extraction from muscle tissue.

Phosphate blends for ham brines contain predominantly long-chained polyphosphates as these phosphates are very soluble in cold water. Hence, activation of protein during production of a ham takes much longer than it would do during production of a sausage. The very soluble phosphates are given many hours during tumbling or mixing to activate protein during ham production.

There are also liquid blends of phosphates on the market which generally contain around 20–25% phosphorus peroxide ( $P_2O_5$ ) (see Section 5.1.3), equalling around 35–40% phosphates. So that the high percentage of phosphates in these blends dissolves in water, potassium phosphates are primarily used. The concentration of  $P_2O_5$ , however, cannot be more than around 27%. If higher levels of  $P_2O_5$  were present in the solution and the solution were stored under cold conditions, phosphate crystals would form and never redissolve.

### 5.1.3 $P_2O_5$ content of phosphates

The  $P_2O_5$  content represents the pentoxide content of a phosphate and is expressed as a percentage. It is a figure which expresses the actual phosphate content of a phosphate without the mineral part such as sodium, potassium or calcium attached to it. As an example, STPP shows a  $P_2O_5$  content of around 58%, meaning that, from the total molecule, around 58% is the phosphate part and sodium accounts for 42%. Even though blends of different phosphates are preferably applied in meat applications, the  $P_2O_5$  content of a phosphate blend does not give any information about the functionality of the blend. As the  $P_2O_5$  content shows the overall percentage of pentoxide content of a blend of different phosphates, it does not reveal the percentage of each type of phosphate present within the blend. Only the proper combination of different phosphates accounts for the functionality inside the meat product afterwards, and this is not expressed by the  $P_2O_5$  content.

## 5.2 Salts (sodium chloride and potassium chloride, citrate, lactate)

Salt, or sodium chloride ( $NaCl$ ) to give it its chemical name, is the world's oldest 'food additive' and generally is the most important additive in the production of meat products.  $NaCl$  is the sodium salt of hydrochloric acid. Most countries in the world classify salt as food and not as an additive. By percentage, salt consists of 39.3% sodium and 60.7% chloride and frequently contains a small amount of anticaking agent in order to keep it free flowing over a period of time. Salt is produced by mining (rock salt) or evaporation (sea salt). Sodium is an essential nutrient and a material which the body cannot produce by itself. Insufficient supply of sodium is a threat to the nerve and muscular system within the human body, while oversupply of

sodium leads to negative effects such as high blood pressure. In solution, sodium chloride hydrolyses into  $\text{Na}^+$  and  $\text{Cl}^-$  ions. The addition of salt to meat enhances the ionic strength and the  $\text{Na}^+$  as well as  $\text{Cl}^-$  ions of salt bind to the ions of the side chains within the proteins and act as a separating force between the side chains (Fig. 5.3).

Chloride is important as it aids potassium absorption in the human body. It is a component of the digestive stomach acid and enhances the ability of blood to carry carbon dioxide from respiring tissues to the lungs. The salty taste of meat products containing sodium chloride originates predominantly from the negatively charged  $\text{Cl}^-$  ions and to a small degree from the positively charged  $\text{Na}^+$  ions. In sodium-reduced meat products, potassium chloride is frequently the material of choice and potassium produces both a salty but also often an undesired bitter taste. The maximum amount of sodium chloride which can be dissolved in 100 g of 20 °C cold water is 35.8 g (a 26.4% salt solution). At this level, the solution becomes saturated as insufficient free water is available to dissolve any further salt. A 26.4% salt solution boils at 109 °C. In frozen food, salt acts as a pro-oxidative and is commonly applied in frozen ready-to-eat meals in an encapsulated form.

Salt fulfils several functions in meat and meat products.

- 1 Salt is a flavour enhancer and no meat dish or meat product tastes good with insufficient salt, even if spices are used in the preparation of the meat.
- 2 Salt, in conjunction with phosphates, solubilizes protein, which in turn can immobilize large amounts of added water and is also able to emulsify fat in meat products. The addition of salt influences the interactions between actin and myosin. These electrostatic interactions are based on negative and positive charges, which attract or repel each other and the addition of salt causes a repelling effect, obtaining larger gaps between actin and myosin. Around 12 g of added salt per kilogram of meat product is the lower limit to activate protein effectively.

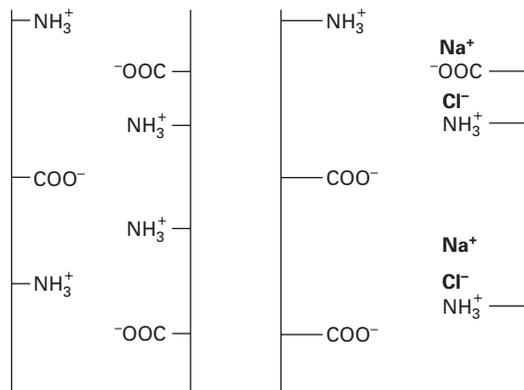


Fig. 5.3 Effect of salt in protein molecules.

- 3 The texture of meat products is also improved by activation of protein.
- 4 Salt lowers the  $A_w$  value (lowers the amount of free water within a product). Therefore in meat products, such as raw fermented salami or raw air-dried products, it is an important hurdle against microbiological spoilage during the initial stages of the production.
- 5 The addition of salt favours the growth conditions for Gram-positive bacteria instead of Gram-negative bacteria. Quite a few pathogens, such as *Salmonella* spp. and *Escherichia coli*, are Gram-negative bacteria.
- 6 Salt itself eventually becomes poisonous to bacteria by creating an electrolyte imbalance within the cell.
- 7 The addition of salt to meat causes a slight move from the IEP of muscle tissue towards a more acidic pH value. Depending on the amount of salt added, the IEP can move from 5.2 to around 5.0. As a result, increased levels of water can be bound without changing the pH value of the meat itself, as the shift of the IEP from 5.2 to 5.0 widens the gap between pH value present in the meat and the IEP. For example, prior to the addition of salt, the pH gap in meat was 0.5 pH units (from 5.7 to 5.2) and after the addition of salt, the gap is 0.7 pH units (from 5.7 to 5.0). A larger gap between the two pH values increases the capillary effect of the muscle fibres and an increased capillary effect causes increased WBC once again.

Salt, or specifically the sodium part of salt, can lead to high blood pressure if consumed in excess. 'Light' meat products are available which have a sodium level of around 450–750 ppm of sodium per 100 g of product (depending on the food legislation in the respective country). In such products, only around 8 g of salt (sodium chloride) are applied per kilogram of product and potassium chloride is introduced instead so that the total level is 12–16 g of salt per kilogram of product. When considering the sodium level of a meat product, it should also not be forgotten that sodium is frequently added to meat products in other forms, such as sodium nitrite, sodium erythorbate and sodium phosphates.

### 5.2.1 Potassium chloride

The disadvantage of potassium chloride is that its bitter taste can be observed in the finished meat product and the majority of people can detect this bitter taste if around 3 g of potassium is present per kilogram of meat product. Three grams of potassium equals around 6 g of potassium chloride given that potassium chloride consists of 52% potassium.

If sodium chloride has to be replaced by potassium chloride, around 15% more potassium chloride has to be applied in order to dissolve protein to the same extent; this is due to the different proportions of sodium or potassium bound to chloride. Chloride ions are mainly responsible for activating protein and potassium chloride demonstrates a non-chloride part of 48% compared with 39% in sodium chloride. As a result, more potassium chloride has to be

added to end up with the same concentration of chloride within the meat product. People with heart problems must not consume high levels of potassium chloride as excess levels of potassium can cause heart irregularities.

### 5.2.2 Lactate and lactate–acetate blends

Lactate is the salt of L-(+)lactic acid and lactic acid is produced via a controlled fermentation of sugar. This must be emphasized as lactate is often confused with lactic acid and there are fundamental differences between the two substances and their function and role from a technological point of view.

Lactic acid, as its name suggests, is an acid and therefore sour within a solution. Being sour in solution, it cannot be introduced into a brine as a lowering of the pH value within a ham brine causes a significant drop in cooking yield of the finished product; the nitrite present within brine would react with the acid as well. Lactic acid added to an emulsified sausage causes a drop in pH value of the sausage mass and every drop in pH value results in reduced yield of the cooked product and also reduced firmness at the same time. In severe cases, a sausage emulsion might totally separate during heat treatment. As stated, the addition of acid causes a drop in pH. As a direct result, the pH is nearer to the IEP of muscular protein and, the closer the pH is to the IEP, the worse the WHC and WBC of the protein itself, as the repulsion forces between actin and myosin are reduced. In addition, as the pH nears the IEP, protein solubility is reduced and less protein is dissolved, lowering the ability of protein to emulsify fat within a sausage or to immobilize added water in a ham.

Lactate is sold in liquid form, as lactate itself is a highly hygroscopic substance and would form lumps quickly if exposed to air and traded as a powder. It is most commonly mixed with around 40% water and therefore the final liquid blend contains around 60% lactate and 40% water. A liquid product is also more user friendly and dissolves more quickly in brine. If lactate is introduced into ham brine, it should be added as the last component, once all other ingredients are already dissolved. In an emulsified sausage, lactate is introduced into the sausage mass within the first third of the cutting process, once all other additives, such as phosphates and salt, have already been added.

Lactate acts against a wide variety of microorganisms such as *Listeria monocytogenes*, *Clostridium botulinum*, *E. coli* O157: H7, *Salmonella* spp., *Staphylococcus aureus*, *Pseudomonas* spp., *Campylobacter* spp. and *Yersinia* spp. Lactate, however, is predominantly used for extending overall shelf life and does not target specific undesired microorganisms.

Lactate is able to extend the shelf life of meat and meat products as it is in equilibrium with lactic acid, once introduced into meat and meat products. Undissociated lactic acid molecules penetrate into the cells of microorganisms and dissociate in the cell into sour H<sup>+</sup> ions (among others), thus lowering the internal pH value of the cell. As a result, a cell senses the alteration and, in

order to stay alive, tries to rid itself of the  $H^+$  ions and raise its own intracellular pH value back to the original level. This process requires much energy, leaving less available for reproduction of the cell and therefore the speed of reproduction is slowed down. Hence, the energy required to remove the  $H^+$  ions from the cell originates from anaerobic metabolism, which causes the formation of lactic acid as well. Therefore, a double acidification of the cell takes place as a consequence of the initial introduction of lactate. Finally, it is also highly energy consuming for the cell to remove the  $H^+$  ions into an extracellular environment already containing  $H^+$  ions. Lactate does not kill bacteria (it is not bactericidal); it only slows their growth (bacteriostatic).

Another effect of introducing lactate into meat products is that  $A_w$  is slightly reduced, because the addition of a salt (lactate is the salt of the lactic acid) binds water in its own right. Lactate immobilizes intracellular water and every cell needs water in order to reproduce. Lowering  $A_w$  results in less free water for microorganisms and therefore growth is slowed once again. Lactate itself can bind around 80% in water of its own weight which reduces the level of free water within a meat product. The introduction of lactate into ham products is another method to make the product safer. Lactate is also applied worldwide within cooked sausages for the same purpose of extending overall shelf life. In some parts of the world, lactate is also applied in fresh sausages and other uncooked injected meat products.

Only recently has sodium lactate also been available in powdered form and in order to combat the hygroscopic nature of lactate, the powdered material contains around 4% silicon dioxide and sometimes around 0.4% oil as well to avoid lumping. A product containing oil cannot be utilized in ham brines but finds applications in sausages. The silicon-containing version can be introduced into brines. Currently, lactate is introduced into meat products as either sodium or potassium lactate. Both versions perform in the same way with regard to the extension of shelf life. The slight disadvantage of sodium lactate is that, by adding this material to meat products, the sodium content from lactate, in conjunction with the sodium coming from salt, enhances the salty taste slightly in the finished product. This problem can be resolved by reducing the amount of salt added by around 0.2% (2 g) per kilogram of meat product or by not changing the amount of salt but applying potassium lactate instead of sodium lactate. Potassium, contrary to sodium, does not in general contribute to the salty taste overall. The recommended usage rate of lactate is between 2.8% and 3.5% (between 28 and 35 g) calculated per kilogram of finished product.

It is difficult to express the extension in shelf life in percentages, but trials, as well as everyday practical experiences, have shown that the following extension in shelf life can be expected by using lactate.

- |   |   |         |
|---|---|---------|
| 1 | Fresh meat and fresh sausages (uncooked), | 30–50%. |
| 2 | Cooked and cured products,                | 30–40%. |
| 3 | Cooked and uncured products,              | 50–90%. |

These values have to be seen in conjunction with other parameters, which have a major impact on shelf life, such as the storage temperature of the product, because the introduction of lactate is just one hurdle in a sequence of different hurdles. Such an extension in shelf life results in fewer returns, a better image and longer production runs for the manufacturer.

The difference between the extensions of the shelf life of cooked cured products and cooked uncured products is because, in cured products, the presence of nitrite, as well as lactate, is an effective hurdle on its own. In uncured products, the nitrite hurdle is not present and therefore the impact of lactate is even stronger.

#### *Lactate–(di)acetate products*

If certain microorganisms are targeted (and, in the case of meat products, *L. monocytogenes* is predominantly the microorganism targeted), a blend of lactate and diacetate (or acetate) is even more effective than lactate on its own. *L. monocytogenes* causes hundreds of deaths worldwide every year; so strict limits are in place in most food standards worldwide to control this microorganism and a strong synergism exists between lactate and diacetate in controlling growth of *L. monocytogenes*. The blends of lactate and diacetate contain around 60% lactate as well as 4%, 6% or 8% of diacetate and the usage rate of a blend containing 4% diacetate is 25–30 g per kilogram of finished product. An increased concentration of diacetate within the blend reduces the usage rate per kilogram of meat product and occasionally a slight taste of vinegar is observed in hams after storage for 6–8 weeks if diacetate was present at 6% or 8% within the blend. Thus, acetate is sometimes used instead of diacetate but, by replacing diacetate with acetate, the impact on *L. monocytogenes* is reduced and this explains why most manufacturers still use a product containing 4% diacetate.

### **5.2.3 Salts of food-grade acids**

Citrate, acetate and lactate are all salts of food-grade acids applied to meat products. Lactate is described in Section 5.2.2 and the other most commonly utilized salt is citrate. Citrate, and here specifically trisodium citrate (TSC) dehydrate, has the E number 331. It is the tribasic salt of citric acid and is produced by the neutralization of citric acid with a strong alkali such as sodium hydroxide and subsequent crystallization. The material is a white powder or granular crystals. It is odourless, tastes salty, is fully soluble in water and has a pH value of between 7.8 and 8.6. TSC is introduced into meat products to enhance the ionic strength, as the amount of solubilized protein correlates to the ionic strength present in the meat product.

Generally 3–5 g of TSC is applied per kilogram of meat product and citrate, unlike phosphates, has no specific effect. Citrate does not remove the links between actin and myosin and it contributes only to the swelling of the muscle fibre structure and not to protein solubilization. Swelling of the

muscle fibre structure supports the immobilization of added water. Given the fact that citrate is alkaline, it also assists slightly in raising the pH value within the meat product, therefore assisting the WHC of protein itself. In most countries, a combination of phosphates with salts of food-grade acids is not permitted.

### 5.3 Hydrocolloids

Hydrocolloids, also commonly referred to as gums, originate from various sources and most of these are not digested in the human digestive system. Carrageenan, alginate and agar originate from seaweed whilst materials such as guar gum, locust bean gum (LBG), cellulose, starch and pectin are of plant origin. Xanthan gum is produced by fermentation and gelatin is derived from animal collagen. Xanthan and guar gum are cold-swelling materials, whilst carrageenan and LBG are hot-swelling materials.

Gums fulfil several functions in meat products.

- 1 By forming a gel or acting as a thickener (depending on the type of gum) they help to reduce cooking loss and therefore assist in increasing yield (Table 5.1).
- 2 The formation of gel assists in obtaining texture in a meat product.
- 3 A higher yield results in a more succulent product.
- 4 Gums assist against syneresis in the finished product.
- 5 Gums do not interfere with the activation of protein within meat products.

#### 5.3.1 Xanthan gum (E 415)

Xanthan gum is a high-molecular-weight cold-swelling gum (polysaccharide), produced by fermentation of carbohydrates by the bacterium *Xanthomonas*

**Table 5.1** Thickening and gelling properties of hydrocolloids

Hydrocolloid	Thickening properties	Gelling properties
Carrageenan	No	Yes
LBG	Yes	No
Pectin	No	Yes
Alginate	Yes	Yes
Agar agar	No	Yes
Xanthan gum	Yes	No
Guar gum	Yes	No
Gelatin*	No	Yes
Carboxymethylcellulose	Yes	No
Modified starch	Yes	Yes

\*Gelatin is not a hydrocolloid but is listed here as it fits the criteria.

*campestris* followed by precipitation in alcohol, drying and milling. The basic structure of xanthan gum is a polymer of D-glucose units with a trisaccharide side chain. This side chain exhibits two mannose units separated by guluronic acid. Xanthan gum is fully soluble in cold water and the negatively charged carboxyl groups ( $\text{COO}^-$ ) on the side chains of the molecule are responsible for the highly viscous fluid obtained once in contact with water. The main function of xanthan gum is to thicken, emulsify and stabilize water-based foods. Within meat technology, xanthan gum is utilized widely for liquid marinades to regulate the viscosity of the marinade. The material is very stable at low pH values (dressings) and high temperatures (retorted products). In fact, xanthan gum is very resistant towards wide variations in pH value from 1 to 13. Xanthan gum also finds an application in small amounts in injection brines for hams in order to delay, or avoid, sedimentation of other materials within the brine, such as starch, thereby keeping all materials well dispersed for a prolonged period of time.

Xanthan gum demonstrates synergistic effects when applied in combination with locust bean gum or guar gum. The synergy between xanthan and guar gum is at its best at a ratio of around 25–30% xanthan gum to 70–75% guar gum. The viscosity of xanthan gum decreases with an increase in temperature and, above 65 °C, the viscosity on the whole is lost. Upon cooling, viscosity quickly returns.

### 5.3.2 Guar gum (E 412)

Guar gum is a cold-swelling gum and a polysaccharide of a white or light-greyish colour. The material dissolves quickly in cold water and increases the viscosity of solutions at very low concentrations. Guar gum originates from the ground seed of the plant *Cyamopsis tetragonoloba* and possesses similar properties to xanthan gum. It is fully soluble in cold water and is a relatively cheap thickening agent compared with xanthan gum. Guar gum contains galactose and mannose in a ratio of 1:2. The linear chain of mannose shows galactose bound to the chain of mannose after every second molecule of mannose and guar gum has up to ten times the thickening power of starch. The molecular weight of guar gum is around 200 000 Da and the material is widely applied in liquid marinades as well as injected meat products such as roast pork, which is sold fresh (uncooked) for the end user to treat thermally at home. Since guar gum is a cold-swelling gum, it assists in holding the injected brine within the meat product and therefore reduces purge in uncooked meat products during storage. Other applications are in soups, sauces and desserts.

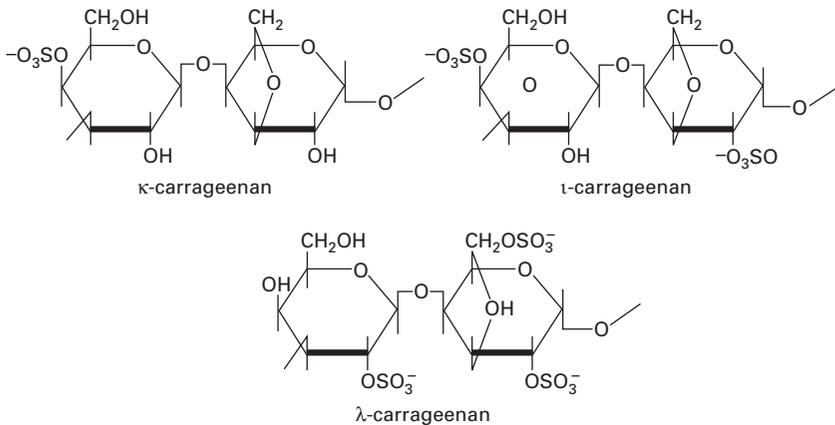
### 5.3.3 Carrageenan (E 407 and E 407a)

Carrageenan is a sulphated linear polysaccharide made from D-galactose as well as 3,6-anhydro D-galactose units and originates from red seaweed

belonging to the class *Rhodophyceae*. The galactose units are linked together via 1–3 and  $\beta$ -1–4 glycosidic bonds. Major producers of carrageenan are in the Philippines, USA and PR China. Carrageenan can bind water in a ratio of up to 1:99 and 1 kg of carrageenan mixed with 99 kg of water forms a gel once heated to around 70 °C and the gel is not heat stable (heat reversible). The production process of carrageenan can be divided into the following steps: harvesting the fresh seaweed → hot extraction in order to separate the plant fibre from carrageenan → removal of the cellulose material first via centrifugation followed by a filtration process → removal of water by evaporation to create a concentrated solution → precipitation of concentrated carrageenan in alcohol (carrageenan is insoluble in alcohol and, as a result, water, alcohol and a coagulum of carrageenan is obtained) → drying of coagulum → grinding → blending → packing.

The three main different types of carrageenan, namely  $\kappa$ -,  $\iota$ - and  $\lambda$ -carrageenan (Fig. 5.4), differ in the positions and number of ester sulphate groups within the molecule, which largely determine the functional properties of each individual type of carrageenan (Table 5.2).

$\kappa$ -carrageenan contains one sulphate group within the molecule and forms a very firm but brittle gel and the strongest gel is obtained by the presence of potassium ( $K^+$ ) ions. Such a firm and brittle gel exhibits syneresis and poor freeze–thaw stability. The gel is stable at a pH value above 4.2. Synergistic



**Fig. 5.4** Different types of carrageenan.

**Table 5.2** Differences between the three types of carrageenan

	Molecular weight	Gel-strength	Viscosity	Syneresis	Elasticity
$\kappa$ -carrageenan	Low	High	Low	High	Low
$\iota$ -carrageenan	Medium	Medium	Medium	Medium	Medium
$\lambda$ -carrageenan	High	No gel	High	Low	High

effects can be achieved by mixing  $\kappa$ -carrageenan with LBG or konjac flour and most  $\kappa$ -carrageenans applied in the meat industry are fully soluble by a temperature of around 68–70 °C. Generally, enhanced levels of cations (potassium originating from potassium chloride) added to carrageenan result in a firmer gel but, at the same time, the temperature for the total solubility of  $\kappa$ -carrageenan rises as well. Hence, there is a limit of potassium chloride added to  $\kappa$ -carrageenan and if this limit (around 27–30% of the total potassium chloride within the blend) is exceeded, the gel strength decreases again.

There are two different types of  $\kappa$ -carrageenan utilized in the meat processing industry: refined and semirefined carrageenan. Refined carrageenan (E 407) contains only around 1–3% insoluble matter (fibre, cellulose or hemicellulose) whereas semirefined carrageenan (E 407a) can contain up to 15% insoluble matter. Therefore, semirefined carrageenan is significantly cheaper and predominantly applied in the production of meat products, either on its own or in combination with a refined carrageenan. The gel strength of semirefined carrageenan is generally higher than that of refined materials but can vary up to 25% given that semi-refined carrageenan is a natural product and no 'standardization' regarding gel strength took place. Gels made from refined carrageenan are smoother and more elastic than a gel made from a semirefined carrageenan. The other significant difference is that a gel made from refined carrageenan is basically clear.

A gel made from semirefined carrageenan is not clear, with some degree of murkiness, caused by the presence of insoluble matter within the gel. However, the gel is never present as carrageenan itself within a meat product, as it is incorporated into the product's protein matrix and therefore the degree of murkiness is hardly detectable within the finished product. Countless different suppliers offer carrageenan, and the degree of insoluble matter within the material varies greatly, as does the colour, which has an impact on the colour of the gel. Carrageenan should be of a light or slightly creamy colour but not grey, yellow or brown. Refined carrageenan is occasionally used in poultry products and is fully solubilized at temperatures as low as 60–65 °C.

$\kappa$ -2-carrageenan is an extract of  $\kappa$ -carrageenan, which forms a strong and elastic gel but shows reduced syneresis compared with  $\kappa$ -carrageenan. The material also solubilizes at lower temperatures (around 62–65 °C) and exhibits better freeze–thaw stability than  $\kappa$ -carrageenan does.

$\iota$ -carrageenan has two sulphate groups within the molecule and forms a soft elastic gel, which is fully soluble between 50 and 55 °C.  $\iota$ -carrageenan is generally not utilized in meat products as it gives a gummy texture to the product.  $\iota$ -carrageenan forms the strongest gel in the presence of  $\text{Ca}^{2+}$  ions, shows very little syneresis and also demonstrates good freeze–thaw stability. A gel made from  $\iota$ -carrageenan is stable at a pH value of 4.2 and above.

$\lambda$ -carrageenan has three sulphate groups within the molecule and acts as a thickener only. The material is cold swelling and does not form a gel.

In summary, an increased number of ester sulphate groups in place of

hydroxyl groups within the molecule makes certain types of carrageenan more soluble at lower temperatures. High-sulphate carrageenan gels also exhibit reduced gel strength at the same time.  $\lambda$ -carrageenan, with three ester sulphate groups within its molecule, does not form a gel at all.

#### *Gelation of carrageenan*

$\kappa$ -carrageenan utilized in the meat-processing industry generally requires a temperature of between 68 and 70 °C to be fully solubilized. Carrageenan is present at such temperatures in a solution as random coils, which form a double helix upon cooling. A gel is formed when the double helices align with each other to form a network, or matrix, which holds water within. Cations ( $K^+$ ), from potassium chloride, are vital in the formation of this alignment of helices and the number of ester sulphates determines how tightly the helices align with each other, ultimately determining the firmness of the gel. The cations act as the connecting link, or bond, within the three-dimensional network of carrageenan coils upon cooling and no gel would be formed if such cations were not present. During cooling of a meat product containing carrageenan, mechanical forces such as squeezing of the product should be avoided to allow the gel to set properly.

Carrageenan should be added to a brine, once the phosphates and salt have already dissolved. The addition of phosphates and salt first into water reduces the surface tension of water thus making it easier to disperse the carrageenan within the brine. If phosphates and carrageenan are present in a complete blend or premix for a ham brine, then this premix is dissolved and/or dispersed first in water followed by salt.

#### **5.3.4 Locust bean gum (E 410)**

LBG originates from the seed of *Ceratonia siliqua* and contains galactose as well as mannose in a ratio of 1:4. A side chain of galactose is bound on every fourth molecule to the linear chain of mannose. LBG is fully soluble at 80 °C, is only thickening if applied on its own and does not form a gel. The molecular weight of LBG is around 300 000 Da and gels made from  $\kappa$ -carrageenan and some LBG demonstrate increased firmness.

#### **5.3.5 Agar-agar (E 406)**

Agar-agar originates from the Malay name 'gel-building food from seaweed'. Agar is a polymer of agarobiose, which is a disaccharide made from galactose and 3,6-anhydrogalactose. It is a creamy white powder which is soluble in hot water but insoluble in cold water.

Formation of gel starts to take place at a concentration of 0.4% and a temperature above 80 °C fully dissolves agar. Upon cooling below 40 °C a gel is formed. Hence, the gel is thermoreversible, meaning that the gel becomes liquid again upon the impact of heat. Agar-agar, a substance high in dietary

fibre (80 g per 100 g), is widely used in the bakery industry, but is also used in retorted meat products such as canned corned beef. Gels made from agar-agar show a high degree of syneresis.

### 5.3.6 Pectin (E 440)

Pectin comes from the Greek word *pektos* meaning compact, thickened or coagulated. Pectin is a component of the cell wall from several types of fruit and vegetable. On an industrial scale, pectin is produced from lemon skin and remains from pressed or squeezed apples. Functionality is determined by the level of ester groups (methoxyl groups) present within the material. A high degree of ester groups (60–70%) causes pectin to gel only below a pH value of 3.5 when there is also a sugar content above 60% at the same time. A low level of ester groups causes the formation of a gel in a wider pH range and with a sugar content between 20 and 60%. Pectin is predominantly used for the manufacture of jam, desserts and fruit gels but also in sauces or gravies in frozen ready-to-eat meals containing meat.

### 5.3.7 Alginate (E 401)

Alginate is the salt of alginic acid and a gum-like derivate from seaweed *Macrocystis pyrifera*. It is made from D-mannuronic acid as well as L-guluronic acid and is applied as a gelling agent or thickener. Blocks consisting of these two acids are present as G- or M-alginate and the ratio of these blocks to each other is 0.5 (G-alginate):2 (M-alginate), or 1:4. A ratio of 0.5:2 demonstrates the strongest gelling properties, whilst other ratios result in reduced gelling. In the presence of calcium ions, alginate forms a heat-irreversible (heat-stable) gel, which is also stable in a pH range between 5.0 and 9.5. This presents a problem for the manufacture of injected meat products as the brine forms a gel soon after the alginate and calcium contact each other within water. Latest developments include methods to delay the instant gelling of alginate by the presence of calcium ions within a brine by 3–5 h. Such a delay would give the manufacturer sufficient time to prepare the brine properly and to inject the meat afterwards without having to work with a high-viscosity brine. If the brine were left standing for several hours, sequestering agents such as polyphosphates would stop the  $\text{Ca}^{2+}$  ions from reacting with the alginate and no gelling would take place for several hours.

## 6

# Additives: proteins, carbohydrates, fillers and other additives

### 6.1 Proteins

Proteins are frequently added to meat products for a variety of reasons. They can stabilize emulsions given that solubilized proteins have hydrophilic (water-loving) and lipophilic (fat-loving) groups within the molecule and therefore they act as emulsifiers, holding two non-mixable phases together during heat treatment. Proteins also bind water on a molecular basis owing to hydrogen bonds within the solubilized protein itself and therefore proteins also help to increase firmness of a product. Some proteins even enhance the flavour in finished products and protein is also occasionally added to meat products to raise the total level of protein in order to fulfil legal requirements.

#### 6.1.1 Caseinate

Caseinate is produced from defatted milk. The milk is heated to around 45 °C and casein is separated by the addition of acid (citric or carbonic acid). The casein is then washed, an alkali (sodium hydroxide) added and the mixture heated to around 85 °C, after which the slurry is dried. The resulting material is soluble caseinate (sodium, potassium or calcium caseinate).

Caseinate accounts for around 80% of the total protein found in milk and demonstrates excellent fat emulsification properties. Rather than binding fat in a three-dimensional gel, it surrounds or covers fat particles and therefore the resulting emulsion is stable even during severe heat treatment such as retorting (sterilizing). High, or varying, temperatures have no, or very little, impact on the ability of caseinate to act as an emulsifier of fat and no other milk protein performs as well as caseinate as an emulsifier in retorted products.

However, the WHC of caseinate is quite limited despite its excellent capacity to emulsify fat. The protein content of caseinate is around 90% and it is fully denatured at around 110–115 °C. Between 1 and 2% (between 10 and 20 g) of caseinate is generally introduced per kilogram of meat product; excess levels of caseinate can lead to the formation of a brown colour during retorting. In an emulsion product such as a frankfurter, caseinate must be added after phosphates, water and salt but before fat. This is because the muscular protein should be activated first before any additional protein is introduced and, once all the protein is activated, then fat can be added.

Stable fat emulsions can be produced using caseinate and low-value fat from beef or pork (e.g. lard, kidney fat or tallow) in a ratio of up to 1:7:7 meaning that, by processing 1 kg of caseinate with 7 kg of fat as well as 7 kg of water, a stable fat emulsion can be obtained (see Chapter 12, Section 12.3). A fat emulsion can replace up to 30% of high-value fat (e.g. pork back fat) in products such as frankfurters without any significant impact on taste and colour of the finished product itself. Replacing high-value fat with a fat emulsion makes proper use of low-value fat which is normally a waste product and may be expensive to dispose of. Care must be taken, however, to ensure that the fat used in the fat emulsion has a low bacteria count. In fermented salamis, a product that is dried for a long time, caseinate is frequently introduced because it develops a typical salami flavour, in conjunction with the meat over time. In general, the flavour of caseinate mimics the flavour of meat very effectively. The disadvantage of caseinate, however, is that it is relatively expensive.

### **6.1.2 Whey protein**

Whey protein is the water phase of milk, once casein has been removed. Its flavour is generally equivalent to that of meat and it also matches the light colour of poultry meat well. The ability of whey protein to gel and the temperature at which this takes place are largely determined by temperatures applied during manufacturing of the whey protein itself (for optimal gelling, the manufacturing temperatures should be kept low). Gelling of a whey protein also depends on pH levels and the concentration of salt within a meat product. Most commonly, whey protein concentrates of around 35% protein are used in meat products. Whey protein concentrates are easy to use in injection brines as they are highly soluble, with low viscosity at the same time. The WBC of whey protein is relatively low, but its gelling capacity is high. Whey protein is also reasonably stable against varying pH values in meat products.

### **6.1.3 Gluten and wheat protein isolate**

Gluten is the common name for the elastic and gummous protein present in wheat, barley, rye, oats and spelt. It is extremely tacky and is almost entirely

made out of two proteins: gliadin and glutenin (gluten). Besides those two major proteins, some albumins and globulins are present as well. Gliadin is tacky whilst glutenin is elastic and hydrated; together, they form a strong three-dimensional network. The proportions of these four proteins vary according to the type of wheat and harvesting time. In most wheat-producing countries, gluten is the cheapest form of protein and is heavily used in the production of meat products such as sausages owing to its excellent WBC and, to a lesser degree, its ability to emulsify fat. This is in spite of the fact that gluten causes an allergic response in certain people. Wheat gluten is also frequently added to sausages to enhance the level of protein within the product.

Wheat gluten contains around 85% protein and the amino acid glutamine is present at a high level. Injectable wheat protein isolate, which contains about 90% protein and is quite neutral in taste and colour, is an excellent additive for injected whole-muscle products as well as all reformed brine-added products and hamburgers as it has very little impact on the natural colour and taste of meat. Injectable wheat protein isolate is highly dispersible in water and does not increase viscosity in brine, therefore making it very easy to inject. The material is also very tolerant against salt and phosphates which is of importance in injected whole-muscle products as it acts synergistically with activated meat protein. Also, applied in high-yield products, wheat protein isolate does not contribute to a rubbery texture in the finished product, unlike hydrocolloids or starch (if used excessively), because the gelling properties of wheat protein isolate are very similar to meat protein. Wheat protein isolate is generally applied at between 1 and 3% in whole-muscle injected products and at up to 4% in meat products such as cooked sausages and hamburgers.

#### **6.1.4 Soy protein**

Soy protein is by far the most commonly applied protein in the meat industry. Soy is not a new food ingredient, having been used for thousands of years in food. The early Chinese, for example, used soy to make tofu, a product which is still produced today. The word tofu means 'meat with no bone' and the level of protein in tofu is around 9%. A soy bean contains around 18% oil, 39% protein, 15% insoluble fibre (dietary fibre), 16% soluble carbohydrate (sucrose) and around 15% moisture, as well as a tiny amount of ash and other compounds. Soy protein has excellent water-binding properties and is also a reasonably effective emulsifier of fat. It also has an extremely high biological value and is easy to digest; there are some health benefits of consuming soy protein as well.

In the past, soy proteins had a bad reputation as the addition of soy to meat products had a negative impact in many cases on the flavour as well as the colour of a meat product. The addition of soy gave the meat product a 'beany' taste and the red curing colour was also affected as the soy proteins

applied were frequently yellow in colour, giving the finished product a slight yellow tan. Those shortcomings, however, are problems of the past and the highly sophisticated soy proteins on the market today are of light colour and have no, or very little, impact on the taste and colour of the finished product. The beany taste was the result of high levels of raffinose and stachyose in the bean and, owing to biotechnological changes, the amount of those substances in soy bean today are greatly reduced. Today, different materials, made out of the soy bean, are used in meat products, including the following.

- 1 Soy flour.
- 2 Textured vegetable protein (TVP).
- 3 Soy concentrates.
- 4 Soy isolates.

The production of soy products is as follows.

- 1 Selected and cleaned soy beans are cracked in order to remove the hull and turned into full-fat soy bean flakes.
- 2 The oil is removed with a solvent and the flakes are dried in order to obtain defatted soy flakes. Defatted soy flakes can be ground into soy flour, from which TVP can be produced. Defatted soy flour has a protein content of around 52% (dry basis).
- 3 To manufacture TVP, the defatted soy flour is mixed with warm water and a slurry is obtained. This slurry is then minced or pressed through differently sized blades to obtain granules of different sizes, which are subsequently dried. The slurry is also commonly coloured in order to obtain meat-coloured TVP granules.
- 4 Soy concentrate is obtained by removing the soluble carbohydrates from the defatted soy flakes. Soy concentrate has a protein content of around 70–72% (dry basis) and consists basically of protein and insoluble (dietary) fibre.
- 5 By removing both the insoluble fibre and the soluble carbohydrate from defatted soy flakes, soy isolate is obtained which has a protein content of 90–93% (dry basis). Globulins such as glycinin (11s) and  $\beta$ -conglycinin (7s) are the major functional components of soy protein, as regards the emulsification of fat and gel formation respectively. The level of protein in a soy product correlates with the ability of the product to emulsify fat and to bind water.

The process is summarized as follows: soy bean → oil removed → defatted soy flour → soluble carbohydrates removed → soy concentrate → insoluble fibre removed → soy isolate.

### *Gelation of soy*

Gelation is the capability to form a gel by producing a structural network and substances such as water, carbohydrates, lipids and others can be immobilized within this three-dimensional network. A gel made from soy isolates is a

three-dimensional matrix and water is held within this matrix. Soy concentrates, however, do not form a gel as the presence of the insoluble fibre inhibits the gel formation; soy concentrates only form a paste. There are major rheological and functional differences between a gel and a paste. Soy gels can be irreversible or reversible (thixotropic) by the impact of heat after gelling. Soy proteins, in order to be fully functional, require sufficient water to be fully hydrated, and the terms solubility, hydration and dispersibility of soy are used interchangeably. Hydration is a chemical–physical process and, by the intensive mixing of water with soy proteins, a gel is obtained (depending on the concentration of protein). Hence, the addition of salt supports solubility of soy protein (very similar to meat protein). Soy isolates are also excellent emulsifiers of fat as they have a high number of lipophilic (fat-loving or hydrophobic) groups within their molecules and can hold fat and water together in a meat product to create a stable network by the addition of energy (such as cutting in the bowl cutter). In whole-muscle injected ham products, soy isolates are applied worldwide in order to add firmness and texture to the product. Hence, soy protein acts synergistically with meat protein and firmness is enhanced through this synergism once again. Different injectable soy isolates exhibit different molecular structures, which determines their dispersibility in cold water as well as their WHC.

In meat emulsions such as frankfurters, both soy concentrates and isolates are used. Here as well, the addition of soy proteins increases firmness, texture and succulence of the product whilst the amount of purge is reduced in packed products as well. Soy proteins are also used in burgers and nuggets worldwide. Binding of meat products such as burgers and nuggets is greatly enhanced owing to the addition of soy and succulence is also enhanced as a result of reduced weight loss during frying. Soy is also occasionally applied for the purpose of protein enrichment of the finished product.

The addition rate of soy proteins to meat products varies considerably and is generally between 0.5 and 3.0% in the finished product. However, emulsified meat products such as hot dogs in places like South Africa or South America can contain up to 13% soy protein. Specialized soy proteins used in the manufacture of low-cost emulsified sausages, burgers, meatballs and nuggets show high gelling properties as those meat products are often produced with only small amounts of muscle meat. The soy therefore contributes to texture and firmness of the product.

Flaked TVP is heavily used in meat products such as burgers, patties, pies and salami in order to imitate lean meat by substituting meat with hydrated flakes of TVP. The dried, and frequently coloured, flakes are usually soaked with water in a ratio of around 1:3 (one part of flakes to three parts of water) and then added to the meat product mostly during the mixing process. These hydrated flakes can hardly be differentiated from ‘real’ meat in the finished product and the addition of flaked TVP in most cases is for cost-saving reasons, given that a TVP–water mix is less costly than lean meat.

Powdered TVP is mostly used for the same reason as flaked TVP to reduce cost of an emulsified product such as a frankfurter. A slurry is generally prepared in a ratio of 1:2.5 and a certain percentage of the slurry is added to a meat product such as a hot dog in place of real meat for cost reasons. The amount of slurry introduced into a meat product depends on the desired 'quality' of the finished product as high levels of added TVP slurry reduce product characteristics such as firmness quickly.

Injectable soy concentrates are used at an increasing rate rather than isolates in injected whole-muscle products as the WHC of a concentrate is only around 20% less than an isolate but the cost of a concentrate, compared with that of an isolate, is significantly less. In general terms, a soy isolate immobilizes water at a ratio of 1:5 whilst a soy concentrate immobilizes water at a ratio of 1:4. The interactions that take place between activated muscular protein and soy protein also take place in the same way regardless of whether the soy is added as a concentrate or as an isolate to an injected meat product. The difference between soy isolate or concentrate in injected meat products becomes even less distinguishable when other additives such as carrageenan and/or starch are applied at the same time.

Soy protein itself, as part of its manufacturing process, is commonly dried directly by the application of direct heat from flames and a small degree of nitric oxide is introduced into the product. As a result, soy proteins can have around 150 ppm of nitrate and up to 45 ppm of nitrite per kilogram of protein. An indirect drying process reduces these levels considerably but is significantly more expensive. Generally, even the addition of 2–3% of soy, containing the above-mentioned levels of nitrate and nitrite, does not cause the formation of a pink colour in uncured products.

Soy protein was, and still is, one of the food substances at the centre of the debate on the genetically modified organisms (GMOs) and leading producers of soy protein have strict quality control measurements in place in order to guarantee that they are producing non-GMO products. Whereas many countries are comfortable with the use of genetically modified (GM) soy, others, such as Europe and Australia, show great resistance towards GM soy protein. Discussions about GM food are often very emotional and unfortunately not often based on facts. Contributing to this situation is the fact that even today there are no reliable and proven studies completed which clearly indicate the effects of GM food on human health. The authenticity of non-GM soy products is commonly examined using polymerase chain reaction (PCR) tests, and/or the entire production of the soy proteins may be covered by an identity-preserved (IP) programme. In a PCR test, a small string of deoxyribonucleic acid (DNA) is replicated many times and modification, as well as the level of modification, of the protein can be seen. Most soy producers also have an IP programme in place in which all stages of the manufacturing process (such as seeding of the bean, harvesting, transport to the processing plant and processing of the soy bean) are closely checked and monitored in order to ensure that non-GM soy never comes in touch with GM material and cross-contamination is excluded.

The threshold level of GM material within non-GM material is primarily determined by the level of detectability, dependent on the latest analysing technology available. Nowadays, the presence of GM material can be detected reliably and with statistical back-up to a level as low as 0.9%. Based on those technical capabilities, most countries have adopted this level. Therefore, in these countries, if a soy isolate contains less than 0.9% of GM material it is called non-GM material, but not GMO free, as the term GMO free would require zero tolerance and the absolute absence of any GM material, which cannot be reliably verified.

### 6.1.5 Egg protein

Liquid full egg consists of around 65% egg white and 35% egg yolk; egg white contains around 11% protein. Most albumins as well as other proteins present in egg white denature by around 60 °C and the proteins present in the egg yolk denature by around 70 °C. Egg white is a very sensitive product from a microbiological point of view and must be treated properly during its production. The bacteria count should be less than  $10^5$  per gram or millilitre and *Salmonella* species 'must not be present in 25 g' (i.e. *Salmonella* spp. must not be detected within a 25 g sample but can be detected, for example, within a 26 g sample). In most countries in the world, terms such as 'negative in 25 g' indicate that something must not be found within a sample of a certain weight. It is important to remember that this does not guarantee an absolute zero presence as the standard refers to the sample of a certain weight only.

Egg white is used in cooked sausages such as frankfurters because of its ability to form a stable and heat-irreversible gel, thus positively contributing to the firmness of low-cost emulsified sausages. The addition rate of egg white varies widely. Around 10–30 g per kilogram of meat product is the general norm and higher inclusion levels result in an egg flavour within the finished product. Egg white is usually stored and sold in a frozen form.

### 6.1.6 Blood and blood plasma

Because of its high protein content and the fact that it gives a natural red colour to meat products, blood is a highly valuable material. The amount of blood within a cow or pig is one twelfth to one fourteenth of its body weight. Blood has a pH value of 7.3–7.5 and contains around 85% water, 3–4% protein and haemoglobin at a value of around 130 g per kilogram of blood. It is the haemoglobin which gives blood its characteristic colour and even an amount as small as 1% of blood added to an emulsified cooked sausage improves the colour nicely. Pig blood has a pleasant red colour, unlike blood from cattle, which tends to be very dark and is commonly brown, or even blackish in colour. This is because cattle are generally much older than pigs at the time of slaughter.

When obtaining blood for use in meat products, the most critical issue is the level of hygiene while collecting blood during slaughtering. Blood, owing to its high water content and pH value, is highly perishable and contaminated blood is a perfect breeding ground for all types of microorganism. Once the blood has been collected, it must be cooled quickly to 3 °C or below and should be stored at around 0 °C. In order to avoid coagulation after collection, an anticoagulation agent such as TSC is added to the blood straight away. Anticoagulation agents act by removing or deactivating components within blood that cause coagulation, which is a complex process. Around 10–15 g of TSC per litre of blood is required to avoid coagulation.

The addition of nitrite does not extend the shelf life of blood greatly. Blood contains a high number of enzymes called oxidases and, as their name suggests, oxidases oxidize added nitrite to nitrate and nitrate is not a hurdle against microbiological growth. At the same time, when storing blood at temperatures below 3 °C, for microbiological reasons, nitrate is not reduced to nitrite any longer as the enzyme nitrate reductase, which reduces nitrate to nitrite, only works at temperatures above 8 °C. Therefore the added nitrite does not have any impact on the extension of the shelf life of blood as it is oxidized, and remains, as nitrate. The most effective way to extend the shelf life of blood is to obtain the blood in the most hygienic conditions possible and then to cool it quickly to 3 °C. It should then be stored at around 0 °C for a maximum of 2 days. Freezing of blood is another way of extending its shelf life.

Blood plasma, rather than blood itself, is occasionally used in the production of cooked sausages and injected and brine-added hams, as blood plasma is highly soluble in water. The gelling characteristics of blood plasma are similar to those of egg white and the gel obtained is heat stable. Plasma starts to form a gel at around 64 °C but only reaches full gel strength at 72 °C. This temperature should be reached as the full-strength gel improves the firmness of a cooked sausage or cooked ham.

Blood consists of around 63% plasma and 37% thick blood (red cells), and plasma can be separated from blood by removing the red blood cells via centrifugation. Thick blood contains predominantly red blood corpuscles and consists of around 36% protein, 2% dry matter and 62% water. Around 65–70% of the total blood is turned into blood plasma, which commonly contains around 7% protein (55% of the protein is globulin and 45% albumin). Based on this figure of 7%, 1 kg of lean muscle meat can be replaced with 3 kg of plasma in a sausage as lean meat contains around 21% protein. Blood plasma also contains around 2% dry matter and around 91% water. To extend its shelf life, blood plasma is commonly turned into frozen chips. If stored chilled, its shelf life at a temperature of 0 °C is only 4–5 days, although salted plasma (2–3% salt added) can be stored for around 6–8 days at 0 °C. Blood proteins have a higher WBC than meat proteins, and blood plasma is introduced at levels of 0.5–2% (5–20 g) per kilogram of meat product. The pH value of plasma is around 7.4–7.8 and the addition of plasma slightly

increases the pH value in the meat product, resulting in an increase in WBC. Blood plasma is dried by spray or roller drying, and roller drying can cause a slight degree of burning. Consequently, dried blood plasma can have a slightly bitter taste. Once the majority of water has been removed during drying, dried blood plasma consists of around 70% protein.

### **6.1.7 Pork rind powder**

Pork rind powder is an animal protein originating from pork rind (skin) and is a completely natural material. The process to obtain pork rind powder includes thermal and mechanical treatment of the skin. Adding pork rind powder to meat products improves their structure and increases firmness and WBC as well as adding some flavour. Different types of pork rind powder have different levels of injectability and some are not injectable at all. The injectable pork rind powders are primarily used in whole-muscle ham products of any kind and should first be premixed with salt, sugar or any other powdered material before being added into the brine for easier dispersion. A high-speed mixer is also of advantage in this process in order to disperse the powders properly. The water used for preparing an injection brine containing injectable pork rind powder must be cold: a temperature of below 5 °C is preferred, as otherwise the particles start to swell and may block filters and needles.

The non-injectable powders have different particle sizes, ranging from 3 mm down to a superfine powder. These are used in emulsified sausages and liver sausages, as well as added-brine hams (hams where brine is added to minced pieces of meat and not injected). Non-injectable pork rind powders frequently contain around 10–13% fat and around 84% protein. If stored at ambient temperatures for a prolonged period of time, the relatively high level of fat in the powder may lead to rancidity. Some types of pork rind powder are also useful in producing fat emulsions in the hot method (see Chapter 12, Section 12.3). The ratio varies from 1:4:4 up to 1:8:8 if a hot emulsion is made by processing 1 part of protein, 4–8 parts of fat and 4–8 parts of water. Most types of pork rind powder have a WHC of between 1:5 and 1:10. Pork rind powder is generally used at a level of 3.0–10.0 g per kilogram of finished product. At these levels of addition the firmness of the finished cooked product increases significantly and a higher cooking yield is obtained at the same time. In addition, the proteins in the pork rind powder also assist in reducing purge in sliced and packed meat products.

Beef protein powders are occasionally utilized as well and most products on the market are non-injectable. These powders are commonly used in brine-added hams, emulsified sausages, patties and other formed products.

### **6.1.8 Gelatin**

Gelatin is produced from collagen-rich material such as pork and cattle skin and bones. The two main methods of producing gelatin use either an acid or

an alkali to solubilize collagen as the first stage. The amount of gelatin obtained from bones is around 3%, while around 22% can be obtained from skin. Gelatin is an odourless powder and a gelatin solution swells as soon as it is heated only slightly. A 3–4% solution generally forms a solid firm gel and in order to form a gel upon cooling, around 0.8% of gelatin is needed within a solution.

Besides being used in meat products such as brawns (meat jellies), gelatin is heavily used in the bakery and confectionery industry. Different types of gelatin result in different gel strengths, which are expressed as bloom values; higher bloom values of gelatin result in firmer gels. The bloom value also correlates with the molecular weight of the collagen molecule and high-bloom gelatin has a much higher molecular weight than low-bloom gelatin. Low-bloom gelatin has a bloom value of 40–100, mid-bloom gelatin a value of around 100–200 and high-bloom gelatin a value of 200–280.

## 6.2 Carbohydrates

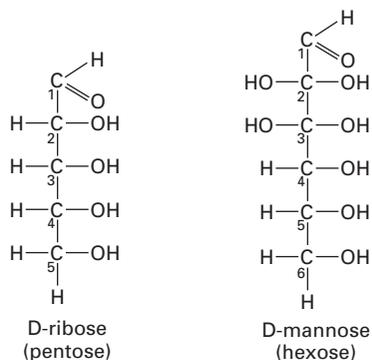
There is a wide range of different carbohydrates. Carbohydrates can primarily be divided into sugars and starches. Sugars can then be classified as monosaccharides, disaccharides and oligosaccharides, while starches can be divided into native and modified materials.

### 6.2.1 Sugars

Sugars are carbohydrates, consisting of carbon, hydrogen and oxygen, and are used in meat products because of their contribution to flavour, their role in browning during the frying process and also their ability to disguise high levels of salt in a meat product. In raw fermented salamis, sugars are introduced as food for starter cultures and are predominantly fermented into lactic acid. It is this lactic acid which primarily causes the drop in pH value in salamis during fermentation.

As already mentioned sugars can be divided into monosaccharides, disaccharides and oligosaccharides. These compounds are collectively known as sugars because of their sweet taste; a polysaccharide, such as starch, is not sweet and is therefore not a sugar. The muscular sugar glycogen, despite being referred to as a sugar, is actually a polysaccharide. Monosaccharides are the simplest sugars, containing three to seven carbon atoms in each molecule. Pentoses such as ribose (Fig. 6.1), xylose and ribulose are monosaccharides with five atoms of carbon in each molecule. Hexoses such as fructose, galactose, glucose, mannose (Fig. 6.1) and tagatose are monosaccharides containing six carbon atoms in each molecule.

Almost all monosaccharides and their derivatives with a ketone or aldehyde group within their molecule have reducing properties (there are a few exceptions such as the derivatives of aldonic acid). These reducing sugars are highly



**Fig. 6.1** D-ribose and D-mannose.

reactive, reacting with amino acids and proteins under the impact of heat and are major contributors to the Maillard reaction (see Chapter 4, Section 4.13). An aldose (polyhydroxyaldehyde) (Fig. 6.2) is a monosaccharide with a carbonyl group ( $\text{C}=\text{O}$ ) on the end carbon forming an aldehyde group ( $-\text{CHO}$ ). If a carbonyl group is on an inner atom, predominantly on the  $\text{C}_2$  carbon, forming a ketone, a ketose (polyhydroxyketone) (Fig. 6.2) is the result.

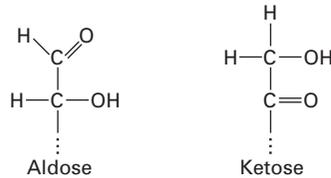
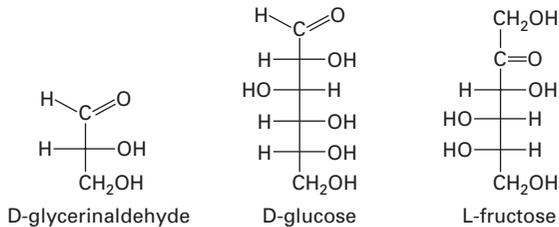
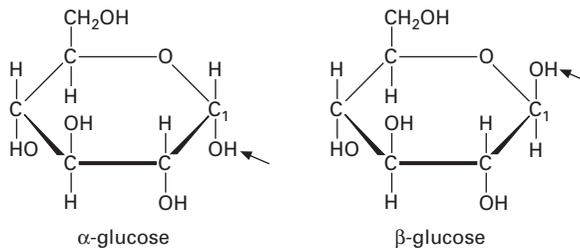
Most monosaccharides can be present in chain or ring form but are present primarily in ring form owing to intermolecular changes resulting in a ring configuration. A five-sided ring such as ribose is known as a furanose whilst a six-sided ring such as glucose is called pyranose.

Monosaccharides are either present in their L or D form, depending on the placement of the OH group by the asymmetrical carbon atom furthest away from the carbonyl group. The reference substance for the L or D form of monosaccharides is D-glyceraldehyde (Fig. 6.3). If the OH group is on the right-hand side (as it is in glyceraldehyde), the D form is present (D originates from the Latin word 'dexter' meaning 'right-hand side'). If, on the other hand, the OH group is located on the left-hand side, the L form is given.

Many sugars differ only in the orientation of the hydroxyl groups (OH) within their molecules, but this small change causes large differences in taste and melting point as well as in biochemical properties. Therefore, in sugars such as D-glucose (Fig. 6.3), a distinction is made between  $\alpha$ - and  $\beta$ -glucose, depending on the position of the hydroxyl group (OH) on carbon atom one in relation to the primary alcohol group ( $\text{CH}_2\text{OH}$ ) connected to carbon atom five. In  $\alpha$ -D-glucose the OH group on carbon atom one is on the opposite site to the  $\text{CH}_2\text{OH}$  group on carbon atom five, while the OH group in  $\beta$ -D-glucose is on the same side as the  $-\text{CH}_2\text{OH}$  within the ring-shaped molecule (Fig. 6.4).

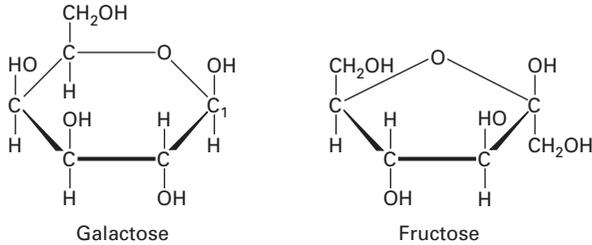
Monosaccharides containing six carbon atoms in each molecule, namely hexoses, are as follows.

1 Fructose (Fig. 6.5) is predominantly present in fruits as well as honey

**Fig. 6.2** An aldose and a ketose.**Fig. 6.3** D-glyceraldehyde, D-glucose and L-fructose.**Fig. 6.4**  $\alpha$ -glucose and  $\beta$ -glucose.

and it is also a component of sucrose (saccharose or table sugar). Fructose is basically not used within meat products owing to its high sweetening capacity.

- 2 Galactose (Fig. 6.5) is part of lactose (milk sugar).
- 3 Glucose (dextrose) is the building block for starch as well as glycogen and is also part of sucrose. During digestion, starch is broken down to glucose and this glucose forms part of blood glucose. Glucose is stored in the human body in the form of glycogen (a polysaccharide) and is found in high concentrations in the liver and in the muscles themselves. Glucose is often used in meat products to round off the flavour. It is also used because it shows a much greater osmotic pressure within a solution than for example sucrose, thus reducing the  $A_w$  further. Glucose shows much less sweetening capacity than sucrose and can therefore be added at higher levels without imparting a sweet taste to the product. Levels up to 2% within the finished product are common. Also, glucose can be directly fermented by most types of starter culture used in the production of raw fermented salami.
- 4 Mannose is another monosaccharide and is present in the skin of oranges.



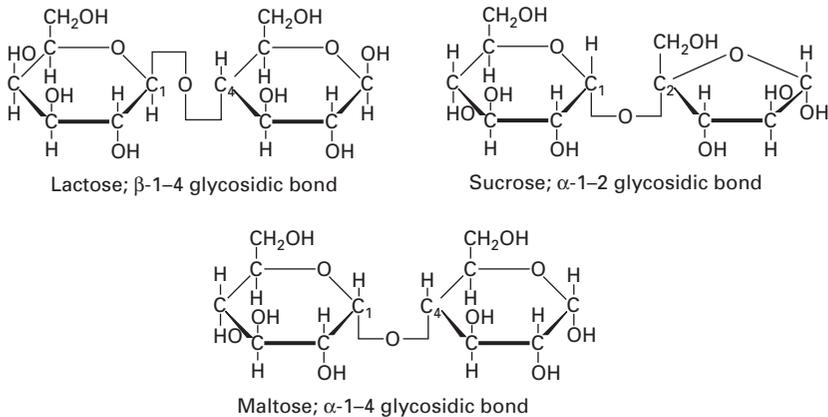
**Fig. 6.5** Galactose and fructose.

Monosaccharides containing five carbon atoms in each molecule, namely pentoses, are as follows.

- 1 Ribose is a component of human DNA.
- 2 Arabinose is part of hemicellulose.
- 3 Xylose is used for the production of the sweetener xylite.

Disaccharides, which are combinations of two single sugars bound together by glycosidic bonds, are as follows.

- 1 Lactose (Fig. 6.6) is a disaccharide consisting of D-glucose and D-galactose units. Cows' milk contains around 4–5% of lactose and human breast milk around 5.5–7.5% lactose. Lactose is used in meat products mainly owing to its compatibility with meat flavour and also in the production of salami. Lactose has a low solubility in cold water.
- 2 Maltose (Fig. 6.6) consists of two D-glucose units. This disaccharide, a product of starch hydrolysis, is highly soluble in water but is not commonly used in the meat industry.
- 3 Sucrose (saccharose) (Fig. 6.6) is a non-reducing sugar and is made from one unit of D-glucose and one unit of D-fructose. Table sugar is sucrose, but sucrose can also be found in raw sugar, syrup, maple syrup, many fruits and honey. Sucrose is present in sugar roots at a concentration of up to 22% and at a concentration of around 20% in sugar cane. Around 2% of starch is occasionally added to sucrose to keep it free flowing. Sucrose is frequently used in cooked ham products at levels of between 0.5% and 1.0% to reduce the  $A_w$  within the product, for its contribution to flavour as well as to disguise elevated levels of salt. Levels above 1.0% often result in an abnormal sweet taste. Caramel is obtained by heating sucrose to above its melting point. Countless other by-products are also obtained during heating of sucrose and they contribute to the distinctive colour, appearance and flavour of a meat product.
- 4 Trehalose also has two D-glucose units like maltose, but both units in trehalose are bound together in a different way from that in maltose.
- 5 Invert sugar, a liquid at room temperature, is sucrose where half of the sucrose is converted (inverted) to a mixture of its basic components, such as glucose and fructose. Invert sugar is sweeter than sucrose.



**Fig. 6.6** Lactose, sucrose and maltose.

- 6 Polyols, such as mannitol and sorbitol, are also disaccharides.
- 7 Brown sugar, a type of sucrose, is made from fine crystals in a layer of molasses syrup (molasses is the concentrated syrup of beet or cane sugar, once sucrose has been removed via crystallization). The amount of syrup coating the fine crystals as well as different processing parameters determine the colour of brown sugar. Increased levels of molasses, for example, darken the colour. Brown sugar gives a meat product a distinctive flavour and is frequently used in hams and ham-like products such as bacon. For honey-flavoured or honey roast products, a blend of D-fructose and D-glucose is usually applied, because these types of sugar are the natural sugars present in honey.

Oligosaccharides have between three and ten monosaccharides in each molecule. The most well-known oligosaccharides are maltodextrins, which are non-sweet. Other oligosaccharides include raffinose, stachyose and verbascose, but these are generally not applied to meat products.

The solubility of a sugar depends mainly on the temperature of the solution containing the sugar as well as the hygroscopic level of the sugar itself. Fructose is most soluble in water, followed by glucose, sucrose and maltose. Lactose is poorly soluble in water.

Table 6.1 shows the different levels of sweetness of various sugars on a per gram basis relative to sucrose, with sucrose having a value of 100.

In general, sweeteners are not often used in the production of meat products as sugars are generally not added to meat products to obtain a sweet taste (except in some Asian products such as lup cheong), rather for the purpose of holding water, rounding off flavour and, to a certain degree, to mask high levels of salt. Sweeteners, however, are occasionally used in marinades and sauces for marinating meat. Aspartame (E 951) is a non-nutritive sweetener and so does not supply any energy. It consists of two amino acids (one of which is phenylalanine) and is around 200 times sweeter than sugar, but the

**Table 6.1** The different levels of sweetness in sugars

Type of sugar	Sweetness
Fructose	172
Sucrose	100
Glucose (dextrose)	75
Xylose	67
Mannose	57
Trehalose	44
Galactose	38
Maltose	31
Lactose	18

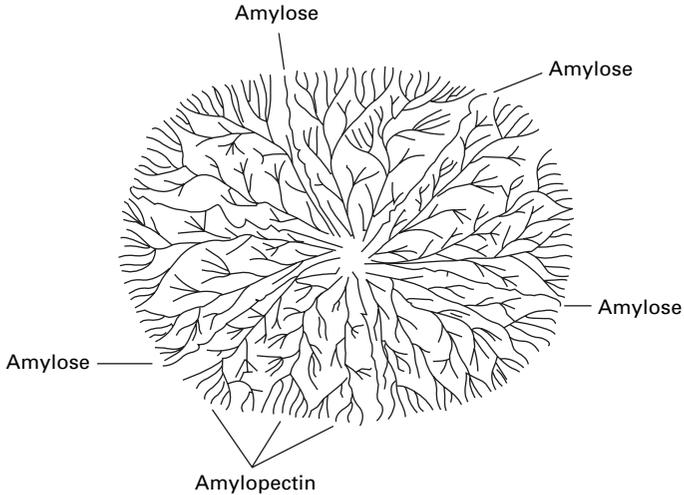
sweetness is lost if food is heated. Therefore, aspartame is primarily used in cold applications such as yoghurts, soft drinks and ice cream. Aspartame is under observation as it may cause neurotoxic effects such as headaches. Cyclamate (E 952) also supplies no energy and is 30 times sweeter than sugar. Large amounts of cyclamate, fed to rats, have been shown to cause bladder cancer, but the effect on humans is questionable: nevertheless, cyclamate is not permitted in the USA. Saccharin (E 954) is another non-nutritive sweetener and is around 500 times sweeter than sugar. It was discovered in 1881 and, in animal tests, saccharin caused cancer. As a result, saccharin is not permitted in many countries, while in others, such as the USA, it is only permitted with a warning on the label. Tagatose is a sweetener with around 90% of the sweetness of sucrose, but at the same time it is extremely low in calories. It is a monosaccharide derived from lactose and is primarily applied in the bakery industry.

### 6.2.2 Starch

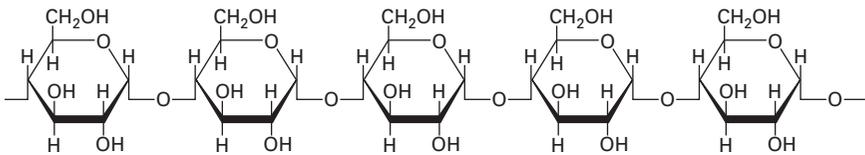
Starch (Fig. 6.7) is a pure carbohydrate polymer and the most common sources are potato, wheat, rice, tapioca (cavassa) and corn (maize). It is also the form in which energy in plants is stored, whereas glycogen is the source of energy for humans and animals. Starch is a polysaccharide and consists of anhydrous  $\alpha$ -D-glucose units containing the elements hydrogen, oxygen and carbon. A starch granule is crystalline and the position of the starch molecules forms radially directed crystals. If polarized light penetrates through a starch granule, the granule is divided into wedge-shaped sections by dark lines, which is known as birefringence. A granule of starch has an organized structure and the amylose and amylopectin that it contains are oriented from the interior outwards.

Starch is non-sweet and contains a small amount of protein as a very thin layer of protein covers each starch molecule. The protein level in starch varies between 0.1% and 0.7% and moisture is present at a level of 12–18%.

The two major components of starch are amylose (Fig. 6.8) and amylopectin. Different types of starch have different ratios of amylose to amylopectin.



**Fig. 6.7** A starch molecule.



**Fig. 6.8** Amylose.

Amylose consists of straight (or linear) chains of 200–15 000 anhydrous glucose units, which are tightly bound together via hydrogen bonding by  $\alpha$ -D-1,4 glycosidic bonds.

Amylose is primarily responsible for the firmness or gel strength of a starch gel as the linear chains of glucose units can align themselves in a parallel way and close to each other. Such an alignment restricts the access of water and enzyme activity is reduced. The tight alignment is also the reason why starches high in amylose require higher temperatures to gelatinize and why enzyme activity during their digestion is slowed; high-amylose starches are known for their low glycaemic index (GI).

Amylose is also very unstable in aqueous solutions, and intermolecular interaction and association with other amylose molecules can lead to an increase in viscosity, retrogradation and even precipitation of amylose particles. Retrogradation in amylose gels is a process whereby the linear amylose molecules align themselves closely next to each other upon cooling and some water, formerly bound within the gel, is released. When a starch slurry in a cooked meat product is still hot, the amylose particles move freely within the hot slurry and the water is immobilized. If the hot starch slurry in the meat product is cooled very slowly, retrogradation takes place; the amylose particles align themselves very closely next to each other owing to their

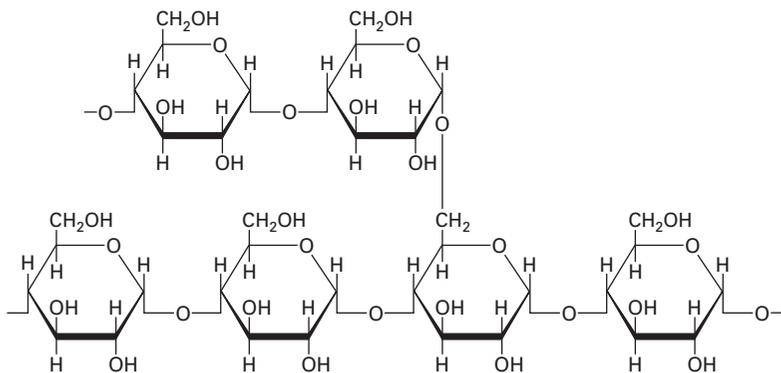
linear structure, squeezing out water. Cooling too quickly, however, also leads to retrogradation as the amylose particles have insufficient time to set up such an organized three-dimensional gel structure. Because of this, a meat product containing starch should be cooled quickly enough to avoid retrogradation caused by slow cooling but should not be placed, for example, into a freezer during the cooling period, as this would also cause retrogradation to take place.

Storage of meat products containing high-amylose starches, at low temperatures from around  $-1\text{ }^{\circ}\text{C}$  to  $0\text{ }^{\circ}\text{C}$  for a prolonged time also favours retrogradation. The level of retrogradation depends on the type of starch and increases in the sequence tapioca > potato > maize > wheat, with wheat starch demonstrating the greatest tendency towards retrogradation. Syneresis and purge (weeping) are seen as a result of retrogradation and this is very common in sliced and vacuum-packed meat products.

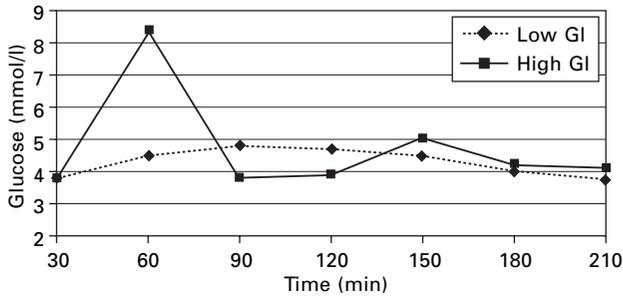
The second major component of starch, amylopectin (Fig. 6.9), also consists of chains of glucose but, unlike amylose, the molecule is highly branched. Short side chains of about 30–35 glucose units are bound to the main amylose–glucose chain after every 20–30 glucose units, resulting in a highly branched structure. The branches open up the molecule and therefore the glucose units are not packed together as tightly as amylose. Amylopectin can have up to  $1.5 \times 10^6$  glucose units per molecule.

Amylopectin is responsible for the elasticity and viscosity of a starch gel and viscosity is primarily a function of molecular weight and particle size. Given that the branched amylopectin is significantly larger than amylose, it builds viscosity better than amylose. Starches high in amylopectin are easier to cook and generally gelatinize at lower temperatures than starches high in amylose. The branching within the molecule also means that amylopectin has less tendency to retrograde.

High-amylopectin starches are easy to digest and have a high GI. The GI demonstrates the immediate impact of a carbohydrate food on blood glucose levels (Fig. 6.10). Sugars with a high GI break down quickly during digestion



**Fig. 6.9** Amylopectin.



**Fig. 6.10** The effect of the GI on blood glucose levels.

and raise the level of blood sugar quickly, whereas low-GI sugars are released slowly into the bloodstream, raise the blood sugar level gradually and are converted into fat more slowly. Examples of high-GI foods are potatoes and white bread; an example of a low-GI food is rye bread. Sugars with a high GI value often contribute to poor health.

Starches, which contain 97% or more amylopectin, and therefore little or no amylose, are collectively known as waxy starches. This type of starch results in clear and transparent gel and does not retrograde primarily because of the high percentage of branched molecules, but also because of the absence of amylose. Waxy starches generally demonstrate good freeze–thaw stability and are also used for heat–freeze processes. Other types of waxy starches contain 99% amylopectin.

Table 6.2 shows the different characteristics of starches commonly used. In general, root or tuber starches swell more rapidly and in a narrower temperature range than cereal starches. Rice starch is the most neutral tasting starch whilst modified tapioca and potato starches demonstrate good freeze–thaw stability. Both also contribute to a smooth mouth feel in a cooked meat product and are frequently utilized in low-fat products as the smoothness from the starch compensates for the lack of smoothness from fat. Modified tapioca and potato starch also gelatinize at lower temperatures, which results in an increased cooking yield in meat products compared with native potato and tapioca starch. Potato starch has a low lipid content, therefore showing little flavour interference with the natural flavour of meat and also has a strong synergistic effect with soy proteins. Native potato starch and tapioca starch, however, are generally very hard to inject into meat products as they show limited dispersibility in cold water, and potato starch also forms a sediment quickly within brines. Modified potato starch produces a firm gel texture and is excellent for use in injected and tumbled meats as well as in marinades for meat. Furthermore, potato starch demonstrates a high peak viscosity and is commonly used in applications where adhesive qualities (batter and marinades) are required.

Native pea starch has characteristics similar to cross-linked modified starches and is also quite robust towards high-temperature treatment, shearing forces and low pH values. Corn starch generally forms a weak and brittle gel.

**Table 6.2** Characteristics of various types of starch

Type of starch	Amylose (%)	Amylopectin (%)	Size ( $\mu\text{m}$ )	Swelling capacity
Potato	21	78	25–80	700
Corn/maize	26	65–70	5–20	24
Rice	20	78	3–8	19
Tapioca	15–18	80–85	5–25	75
Wheat	27	75	25	21
Waxy maize	2	95–98	5–25	65

Granule size does not have a significant impact on the performance of starch. It is predominantly how fast a starch gelatinizes as well as the final gelatinizing temperature which determines functionality to a large degree. In general, the swelling of a starch molecule under the impact of moist heat takes place more rapidly in larger molecules, such as tapioca. In larger starch molecules in the presence of heat, the linear structure of amylose within starch lines up readily and there is an increased level of hydrogen bonding. As a result, more energy is required to break the bonds within high-amylose starch and gelatinize the material.

Starches also contain phosphorus in various forms and the nature of the phosphorus affects the performance of starch. In most cereal starches, phosphorus is present as lysophospholipids, which will form a complex with the amylose, therefore reducing the WBC, which results in an opaque paste. The viscosity of starch in solution is expressed in Brabender units. It is also of interest that heating starch quickly compared with slowly, but reaching the same final temperature, results in a more viscous slurry.

### *Modification of starches*

Native, or unmodified, starches are obtained from the original form of the starch-bearing material. Native starches exhibit generally limited resistance towards low pH values in food, the impact of heat during processing and poor performance regarding freeze–thaw stability. Therefore, modification of starch is common practice in order to improve the behaviour of starch towards such processing parameters. Modified starch is ordinary, or native, starch altered physically or chemically to modify its functional properties such as thickening or gelling.

Physically modified starch undergoes various processes such as drum drying, extrusion and spray drying in order to obtain pregelatinized, agglomerated or cold-water-swelling starches. Within those physical processes, no ‘chemicals’ are applied and such modified starches maintain their ‘clean image’. Pregelatinized starches are cold swelling and do not require much heat in order to thicken or form a gel or paste. They are commonly obtained via spray drying, drum drying or extrusion from modified or native starch. Pregelatinized starches develop viscosity in cold and warm water and have

been gelatinized already before being dried again to obtain the material in a powdered form. Pregelatinized starch is also known as precooked, pregelled, instant or cold-water-swelling starch.

Chemically modified starch is treated with 'chemicals' and commonly some hydroxyl groups within the molecule are replaced with either ester or ether groups. Modification takes place primarily in the form of cross-linking as well as substitution and larger molecules are obtained. As a result, those modified materials are more robust towards the impact of processing parameters such as low pH values, high temperatures and freeze–thaw cycles. Cross-linking with materials such as phosphorus oxychloride enhances resilience towards acidity as well as high processing temperatures and is a process in which two hydroxyl groups of neighbouring starch molecules are chemically linked together. Other ways of chemical modification are substitution or oxidizing.

Substitution within the starch molecule with acetyl or hydroxypropyl increases freeze–thaw stability and reduces also the level of retrogradation. Highly substituted starches result in water-soluble materials and some starches are dual modified, cross-linked and substituted. Oxidation of starch enhances crispiness in certain foods such as cereals and oxidized starches are commonly not applied in meat products.

Cellulose is a glucose polymer and generally the main component of cell walls. The enzyme amylase can break down starch into glucose units but cannot break down cellulose, and only the enzyme cellulase can break down cellulose into its basic components. Carboxymethyl cellulose is normally insoluble in water but made water-soluble through modification. This is achieved by the introduction of active methyl, hydroxyl or propyl groups on to the OH group of the cellulose.

### *Gelatinizing of starch*

Once starch in water or in a meat product is heated under moist conditions, water penetrates into the starch granule until fully hydrated. Root and tuber starches swell more rapidly in a narrower range of temperatures than cereal starches. Upon full hydration, the hydrogen bonds between amylose and amylopectin maintain the integrity of the granule and the granule begins to swell from the inside out upon the continued impact of heat. During swelling and hydration, the size of the starch molecule increases several times. Birefringence is lost, the solution becomes clearer, consistency increases dramatically and a peak is reached. The gelatinization end point is reached when 96–98% of the granules have lost their birefringence. The optimal temperature for complete gelatinizing varies between the different types of starch but is generally higher within starch exhibiting a higher content of amylose, given that the amylose molecules are of linear structure and tightly aligned next to each other. Upon subsequent cooling, a paste or gel is obtained. The gelatinization point of potato starch is between 61 and 63 °C, tapioca between 65 and 66 °C, corn starch between 67 and 69 °C, rice starch between

72 and 74 °C, pea starch between 72 and 76 °C and wheat starch by 75 and 77 °C.

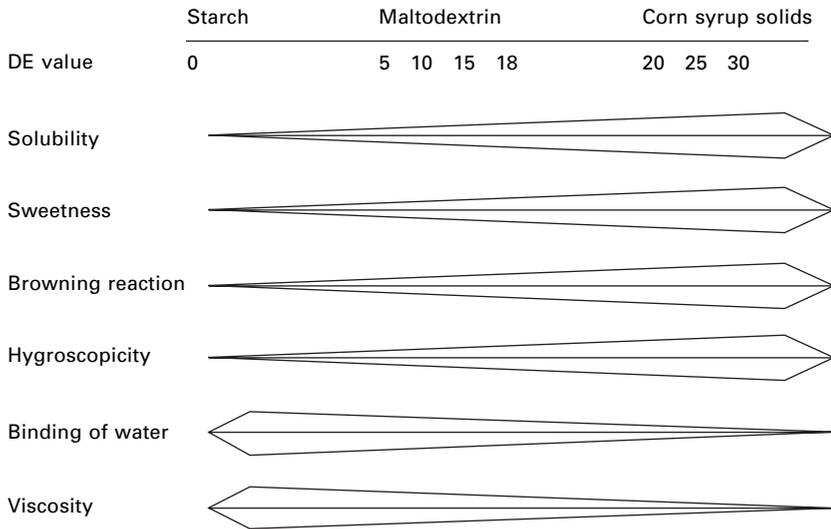
#### *Freeze–thaw stability of starch*

Starches exhibiting good freeze–thaw stability should contain a high level of amylopectin, and starches which have been acetylated, modified with phosphorus oxide (phosphorus oxide stabilized) or cross-linked perform well. Some highly freeze–thaw-stable starch is modified with phosphorus oxide as well as heavily cross-linked. Waxy starches are commonly applied in sauces and soups, which are stored frozen. Meat products, containing starch and being stored frozen, should be produced by the help of waxy starch as well in order to avoid, or reduce, syneresis during thawing. Despite that, some native starches such as waxy rice starch demonstrate better freeze–thaw stability than high-amylopectin and modified starches, which cannot be scientifically explained yet. In particular, modified tapioca and potato starch demonstrate excellent freeze–thaw stability. Most native starches such as wheat and potato starch demonstrate very poor freeze–thaw stability and a mixture of 50% native starch and 50% (or more) of a modified starch, high in amylopectin, results in a greatly improved behaviour towards freezing and thawing. Starches with the E numbers 1412, 1414 and 1442 exhibit excellent freeze–thaw stability and all are modified basically with the same chemicals but in different ways or methods.

### **6.3 Fillers: maltodextrin, flour, wheat fibre, konjac, cereal binder and rusk**

Starches (Fig. 6.11) are converted into countless other commercial materials by hydrolysis with enzymes or acids, or by thermal treatment. The materials obtained are assigned a dextrose-equivalent (DE) value (or dextrose content), which represents the degree of conversion or hydrolysis. More specifically, the DE value is a measure of the amount of reducing sugars present in a material calculated as dextrose and expressed as a percentage of the total dry substance. Higher DE values correlate with a higher proportion of low-molecule sugars (six-carbon-atom sugars) and refer to the percentage of reducing sugar calculated as glucose on a weight basis. Starch demonstrates a DE value of zero and is non-sweet whereas dextrose has a DE value of 100.

Maltodextrins (Fig. 6.11) are produced from starches broken down into smaller chains and are polysaccharides with different lengths of glucose chains. They exhibit a DE value below 20 and are non-sweet. Maltodextrins are frequently used as bulking agents or as carriers for other ingredients such as spices in dry blends of powders. Hence, if they are introduced into products such as cooked ham, the dry-matter content is increased, generally leading to a slight increase in cooking yield as well.



**Fig. 6.11** Characteristics of starch, maltodextrin and corn syrup solids.

Glucose syrups such as corn syrup solid (Fig. 6.11), which is made from corn starch, have a DE value (dextrose content) between 20 and 50 and taste more or less sweet, depending on their DE value. Monosaccharides and oligosaccharides with varying chain length make up the remainder of the syrup. Glucose syrups show similar characteristics to glucose but are significantly less expensive. The degree of sweetness depends on the dextrose content with syrups showing a DE value between 40 and 60 already tasting slightly sweet. Corn syrup solids are produced by spray-drying or drying in a vacuum. Maltodextrins differ from syrups in that they have a higher oligosaccharide content and a higher molecular weight. Oat-based maltodextrin, produced by the enzyme amylase, produces a fat-like gel in meat products such as cooked sausages and is used as a fat replacer. Low-DE-value syrups have the highest average molecular weight and are the least hygroscopic. On the other hand, high-DE-value syrups have the lowest average molecular weight and are the most hygroscopic and sweetest materials. Corn syrup is regularly used in sausages and hams to cover up a possible salty taste as well as to increase the dry-matter and content in a product. This is also very economical as corn syrup is quite inexpensive.

Flour is the milled grain of cereal and contains around 5–15% protein, 70–75% starch and 10–15% water. If the original source is wheat, barley or oats, the flour will contain gluten, which must be taken into account as some people are allergic to gluten. Flour assists in absorbing water in the uncooked stage in a meat product primarily through the activated protein present within flour as well as the capillary effect.

Wheat fibre is produced from the stem of wheat and therefore does not contain gluten. It is also neutral in taste. Two different wheat fibre products

are used in processed meats: one is a fibre product used in emulsified sausages such as hot dogs as well as in products such as meatballs, burgers and patties, and the other is an injectable product. The main difference between the two types of fibres is the length of the fibre itself. The injectable product is around 40  $\mu\text{m}$  long and is much shorter than the fibre used in emulsified products, which has a length of around 220  $\mu\text{m}$ . The thickness of both types of fibre is around 25  $\mu\text{m}$  and wheat fibres are almost insoluble in water as their insoluble dietary fibre content is above 90%. Wheat fibres, and also all other fibres, help to retain moisture owing to the capillary effect and therefore cooking yield can be increased slightly in emulsified products such as hot dogs and meatballs which include wheat fibres. The firmness of meat products is also enhanced if fibres are introduced.

Weight loss during the grilling of frozen burgers (which are put on the grill in a frozen state) can be reduced through the incorporation of fibres. Compared with burgers without fibre, these burgers are more juicy and succulent when cooked. Because of the higher moisture content of the burger with added fibre, the product also cooks, or fries, better and burns less on its surfaces when grilled.

Insoluble fibre also creates a three-dimensional network within meat products, especially in sausages, where there are high shearing forces. Moisture is bound within this network and a more succulent and juicy product is obtained.

When emulsified sausages are stored frozen, loss during thawing can be reduced by the presence of wheat fibre and a juicier product is the result. Generally, 1–2% fibre is introduced into the recipe of an emulsified sausage, burger or meatball.

Another application of wheat fibres is their injection into whole-muscle products such as pork ham. Injectable wheat fibre is easy to disperse in brines and does not block needles. In whole-muscle ham, the fibre fulfils a similar function as in a sausage, holding moisture and therefore increasing cooking yield; the firmness of the product is enhanced as well. Injectable wheat fibre is applied at around 0.7–1.5% within the brine. In highly injected whole-muscle hams, where the level of injection varies between 50 and 90%, the use of wheat fibres is not always justified as other materials such as carrageenan, soy proteins and different types of starch are more effective. However, in low-injected whole-muscle hams, where the level of injection is between 20 and 35%, the introduction of wheat fibre, in conjunction with phosphates and salt, results in an excellent product with regard to cooking yield, firmness and sliceability.

Konjac (E 425) is used widely in Asia and is a water-soluble dietary fibre originating from the root of the konjac plant *Amorphophallus konjac*. Other names for konjac are 'konnyaku' in Japanese and 'moyu' in Chinese. Konjac, a polysaccharide, is obtained by grinding the tuber (root) of the konjac plant. The material is classified as a glucomannan and consists of glucose and mannose in a ratio of 5:8. The basic polymeric unit of Konjac has the

configuration GGMMGMMMMMGGM, where G represents glucose and M mannose. Konjac forms extremely viscous and pseudoplastic solutions and has the highest molecular weight of any dietary fibre, 200 000–2 000 000 Da. Konjac also has the highest WHC of any soluble fibre and can hold up to 80 times its own weight in water. It forms non-reversible gels and also acts synergistically with materials such as carrageenan, xanthan gum and starch.

The application of konjac is slightly 'difficult' as the material has to be treated separately first before it can be applied into meat products. More specifically, konjac powder is most often mixed first with around 30–40 parts of water and an alkali such as sodium carbonate or sodium hydroxide is added to obtain a viscous paste. Around 20–40 g of sodium carbonate or sodium hydroxide are generally added per kilogram of konjac. The added alkali neutralizes the acetyl group on the molecule which is required for konjac to form a heat-stable gel, once the paste is thermally heated. The neutralization of the acetyl groups requires around 12 h under chilled conditions and around 2–4 h at room temperature. Larger amounts of added sodium carbonate or hydroxide speed up the process of neutralizing the acetyl groups on the molecule. The pH value of the konjac paste has to be above 9.5 in order to form a gel during heat treatment and the amount of paste added to meat products such as meatballs varies between 1 and 5% to increase the firmness of the finished product.

Cereal binder is produced from ground grains (mostly wheat grains). The cereal grains are not highly processed to produce cereal binder, some of the husk is simply removed and therefore care has to be taken when using cereal binder in meat products, as the microbial count can be high. The level of protein in cereal binder is 12–15%.

Cereal binder is frequently utilized as filler in low-cost emulsified products such as frankfurters and hot dogs as well as in low-cost burgers and patties. The addition rate varies greatly and is commonly between 20 and 50 g per kilogram of finished product. Excess use results in a sandy and bread-like taste in the meat product.

Rusk is produced from wheat flour which has been chemically raised, baked and ground. It can hold four to five times its own weight in water and can be added to a sausage presoaked, or in a dry form. Rusk contains around 9–12% protein, 1–4% ash, 2–5% moisture, 0.5–2% fat and 75–85% carbohydrate.

## 6.4 Preservatives in meat products

Preservatives are introduced into meat products to extend shelf life and, despite the common understanding that all additives used in meat products must be of no threat to human health, different countries permit the use of different substances as preservatives. The majority of preservatives are bacteriostatic and inhibit, delay or retard bacterial growth, but some are even

bactericidal and as such kill bacteria. A wide range of substances are preservatives including organic acids, carbon dioxide (CO<sub>2</sub>), different salts, antibiotics such as nisin and natamycin (see Chapter 16, Section 16.2.3) and smoke (see Chapter 6, Section 6.11). Mineral acids (phosphoric acid) and inorganic anions such as nitrite and sulphite also demonstrate preserving aspects. Some common preservatives are described below.

Nisin, a polypeptide made from *Lactococcus lactis*, is permitted in some countries as a preservative and is also an antibiotic. It is effective against most Gram-positive bacteria such as *Clostridium* spp., lactic acid bacteria and *Bacillus* spp.. Natamycin (pimaricin) is produced by *Streptomyces natalensis* and is applied to dried sausages such as salami to prevent growth of mould. CO<sub>2</sub> acts particularly well against Gram-negative bacteria such as *Pseudomonas* spp. forming carbonic acid in conjunction with water from meat or meat products and also inhibiting enzyme-catalysed reactions within cells. Therefore, CO<sub>2</sub> also causes disruption of cell membranes, delaying bacterial growth further.

Two other commonly applied preservatives are benzoic and sorbic acid and their salts, which are benzoate and sorbate, whilst propionic acid (propionate) is rarely applied in meat products. Benzoic acid acts predominantly against yeasts and moulds and performs best at pH values of 2.5–5.0. Sorbic acid is 2,4-hexadienoic acid and also acts against moulds. These three acids act best as preservatives in their undissociated state at pH values between 2.2 and 2.8, which are not found in meat products. At pH values of 6–7, all these three acids are fully dissociated and only the undissociated form of the acid acts as a preservative. In meat and meat products, pH values around 5–6 are generally found and around 40% of these acids are present in an undissociated state at such pH levels acting as a preservative. Sorbate is regularly utilized in a dipping solution during salami manufacture. The freshly filled salami is dipped for a few seconds into a 10–15% solution of potassium sorbate and this dipping process prevents to a large degree growth of unwanted mould during fermentation. As well as preservatives, a high standard of hygiene and good manufacturing practice also help tremendously to extend shelf life of meat products.

#### 6.4.1 Sodium metabisulphite

Sodium metabisulphite (SMBS), the commercially produced salt of sulphurous acid, is a preservative used to extend the shelf life of meat products such as fresh sausages and burgers, even though it can have adverse effects on some people, especially asthmatics. SMBS is not permitted in several countries for use in meat products. Chemically, SMBS contains 67% sulphur dioxide (SO<sub>2</sub>). When SMBS is applied to a meat product, the SMBS instantly reacts with water and, as a rule of thumb, around 50–55% added SMBS can be found analytically in the meat product as SO<sub>2</sub>. Some SO<sub>2</sub> is 'lost' as a result of countless reactions and cannot be detected any longer. Therefore meat

products are not analysed with regard to their SMBS content. The level of  $\text{SO}_2$  has to be measured instead and food standards refer to the  $\text{SO}_2$  level, rather than the SMBS level, of a product. In countries such as Australia and New Zealand, 500 ppm of  $\text{SO}_2$  is the maximum per kilogram of fresh sausage. In the UK, SMBS is permitted in certain meat products only and it is not permitted in most other countries within the EU. One of the reasons that it is not permitted in some countries is that SMBS causes a significant loss in vitamins such as thiamin in foods.

The degradation of  $\text{SO}_2$  within a meat product depends primarily on the microbiological status of the meat and fat materials used and on the storage temperatures that the meat product is exposed to. Excess levels of bacteria in a fresh meat product rapidly reduce the level of residual  $\text{SO}_2$  in a fresh meat product, such as a fresh sausage, and shelf life overall is considerably shortened. Elevated storage temperatures also reduce the level of SMBS within a fresh sausage significantly and shortened shelf life is the result. SMBS is more effective against Gram-negative such as *Enterobacteriaceae* than Gram-positive bacteria. SMBS is also more effective at low pH values.

As explained above, most food standards worldwide express the level of SMBS present in a meat product as  $\text{SO}_2$  and around 50–55% of added SMBS can be found as  $\text{SO}_2$  in the finished meat product straight after producing a meat product such as fresh sausage. As an example, 500 ppm of  $\text{SO}_2$  would generally be obtained by adding 1.1 g of SMBS to every kilogram of uncooked meat product. By adding SMBS to meat products such as fresh sausage,  $\text{SO}_2$  is produced in an acid environment (as is the case in meat products) from SMBS ( $\text{Na}_2\text{S}_2\text{O}_5 \rightarrow \text{SO}_2$ ).  $\text{SO}_2$  is absorbed into bacterial cells and reacts with water in the cell. Sulphurous acid is obtained ( $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$ ), which is not stable and falls apart by donating hydrogen ions ( $\text{H}_2\text{SO}_3 \rightarrow \text{HSO}_3^- + \text{H}^+$ ). In a subsequent reaction, negatively charged  $\text{SO}_3^-$  ions are obtained ( $\text{SO}_3^{2-} + 2\text{H}^+$ ) as well. Sulphurous acid, whilst present as an acid, acts as a very strong preservative and the undissociated acid molecule is the active agent. The optimal pH value for maximum effectiveness of sulphurous acid as a preservative would be 5.1 because it would then be present in its undissociated form. However, such low pH values are generally not found in meat products as protein activation and WBC are very poor at such pH levels (IEP).  $\text{SO}_2$  on its own also interferes with the enzyme structure of bacterial cells.

Besides  $\text{SO}_2$ , sulphurous acid is present in different levels of dissociation as  $\text{H}_2\text{SO}_3$ ,  $\text{HSO}_3^-$  and  $\text{SO}_3^-$  at the same time.  $\text{SO}_2$  and sulphurous acid have a strong impact on bacterial growth whilst hydrogen sulphate ions such as  $\text{HSO}_3^-$  ions act as weak antibacterial agents. Sulphate ions such as  $\text{SO}_3^-$  have a fairly weak impact on bacterial growth. Sulphite ions are reducing agents with a lone pair of electrons, which makes them highly reactive and they form bonds with a wide range of other substances present inside the cell. They also bind to oxygen and create radicals, which interfere in many different ways with processes inside the cell such as protein synthesis and DNA

replication, systems of energy production and activities of cell membranes. Generally, at least 150 ppm of  $\text{SO}_2$  has to be present in a meat product to have a significant effect in extending shelf life. The introduction of SMBS into cooked meat products such as sausages and hams is occasionally practised but has little effect in extending the shelf life of these products after heat treatment.

SMBS controls bacteria growth and even kills bacteria to a certain degree prior to thermal treatment but, once a meat product is cooked and all proteins are denatured, the impact of residual SMBS in the cooked meat product regarding the extension of shelf life is negligible. This is because SMBS requires free water to form  $\text{SO}_2$  and water is already bound solidly in one way or another in the cooked product. Hence, all vegetative bacteria are killed and SMBS has no impact against spores, which have survived pasteurization. SMBS also improves and stabilizes the colour of fresh sausages as it is a reducing agent donating electrons and as such slowing the oxidation of myoglobin into metmyoglobin as well as reducing metmyoglobin into reduced myoglobin. The formation of metmyoglobin is greatly delayed and reduced as a consequence. Metmyoglobin causes a brownish-grey colour in meat product and the presence of  $\text{SO}_2$  helps to maintain the 'original' red colour. Experts describe this by saying that the 'bloom' of the sausage is maintained.

## 6.5 Monosodium glutamate

Flavour enhancers are substances that have no taste or flavour of their own but stimulate the surface of the tongue and enhance the formation of saliva. As a result, the flavour of food in presence of a flavour enhancer is perceived in a more pronounced way. It is believed that the Chinese used the flavour enhancer monosodium glutamate (MSG) as early as 2000 BC and it has since been used in food products for centuries. MSG is the monosodium salt of glutamic acid, one of the amino acids, and consists of water, sodium and glutamate itself. Glutamic acid also functions as a building block for almost all proteins, plays an important role in building muscular structure and is an interim product in numerous metabolic processes. It occurs naturally in plants such as seaweed, soy beans and sugar beets and is usually made by fermenting corn sugar, starch or molasses from cane or sugar beet.

To obtain the desired effect as a flavour enhancer, glutamate must be present in its L configuration. In food with a pH value of 4.5–8.0 (all meat products fall into this range), if MSG is present in a concentration of 0.2–1.0%, a pleasant, slightly sweetish as well as salty taste will develop, enhancing the food's own taste. The flavour-enhancing effect of MSG is ultimately based on the level of dissociated glutamic acid within a product and the level of dissociation depends on the pH value. Glutamic acid is completely dissociated by a pH value of 7.1 and is only dissociated to around 40% at a pH value of 4.6. In meat products, where generally a pH value of 4.6 (low pH

for a fermented salami) up to around 6.2 is found, the flavour-enhancing effect of MSG becomes more pronounced at a higher pH value.

In addition to the four traditional taste perceptions such as salty, sweet, sour and bitter, the evasive 'umami' taste was created to best describe the contribution of MSG to the taste of food. This specific 'umami' taste plays a vital role in the acceptance of food in Asia, with umami being interpreted as savoury or delicious. MSG enhances meaty and salty flavours, reduces bitter notes and has no or very little impact on notes of sweet and sour in meat products or other foods. MSG is believed to be responsible for the 'Chinese restaurant syndrome', symptoms of which are a slight headache, nausea, chest pain and tingling in the facial areas as well as the neck. Only around 1.5% of the total population, however, is susceptible to this kind of syndrome and then only if quite a high amount of MSG is consumed on an empty stomach. At typical usage levels of around 0.5–2 g per kilogram of meat product, the consumption of MSG, even on an empty stomach, hardly causes any problems.

## 6.6 Ribonucleotide and other flavour enhancers

As a replacement for MSG, flavour enhancers such as inosine-5-monophosphates of sodium, potassium and calcium (E 631, E 632 and E 633 respectively) are used. These flavour enhancers are applied at a very low level (0.007–0.05%) in the final product but are frequently mixed with MSG to achieve the specific umami taste (MSG taste) and, when applied on their own, no umami taste is produced. Examples of flavour enhancers in this group are disodium guanylate (E 627) and disodium inosinate (E 631), also known as 5'-guanylate monophosphate and 5'-inosinate monophosphate respectively.

GMP and IMP together are known as ribonucleotide and carry the E number 635. Ribonucleotide has a 40–50 times stronger flavour-enhancing activity than MSG and is also naturally present in meat at around 0.02%. A mixture of 19 kg of MSG with 1 kg of ribonucleotide provides the same flavour-enhancing effect as 100 kg of MSG on its own as a strong synergistic effect is seen between those two materials.

Taurin, a semi-essential amino acid, was once promoted as a flavour enhancer but was never commercially successful. Alapyridaine, a flavour enhancer isolated from beef broth, enhances the taste of sweet, salty and other piquant tastes, influencing more than one sense of taste at the same time. It has not yet been applied in meat products, however.

## 6.7 Water

Water as such is not an additive but it fulfils major technological functions in meat products. A molecule of water is made from two hydrogen atoms and

one oxygen atom. By weight, the oxygen is eight times heavier than the hydrogen within a water molecule and the two atoms of hydrogen are bound to the oxygen at an angle of  $108^\circ$ . Because the hydrogen atoms are bound to oxygen at an angle, water has its highest density at  $4^\circ\text{C}$  and therefore ice floats on water. Water is a polar molecule and in polar molecules, there is an unequal distribution of charges. The polar nature of water makes it a suitable medium for living cells.

Different levels of hardness are found in water and hardness can be divided into temporary or permanent hardness. The degree of hardness of water is determined by recalculating the amount of salts from calcium and magnesium present in water into milligrams of calcium oxide per litre of water. One degree of German hardness ( $1^\circ\text{dH}$ ) equals 10 mg of calcium oxide in 1 l of water. Other countries may use other values and other scales to express hardness of water but the basis is the amount of calcium oxide in milligrams per litre of water.

Table 6.3 shows the values of total hardness (permanent and temporary) of water for various categories of soft and hard water. Temporary hardness is caused by the presence of calcium or magnesium hydrogen carbonate ( $\text{HCO}_3^-$ ), which evaporate out of water upon heating. Permanent hardness is found when the calcium or magnesium is not present as hydrogen carbonate but as chloride, nitrate, phosphates or sulphate and these substances remain in the water after heating.

Hard water can interfere with the functionality of phosphates in brine. If hard water (180 mg of calcium oxide per litre of water or above) is used for a ham brine which is injected into meat at 15–20%, the brines would usually contain around 5–6% phosphates. Negatively charged phosphate anions form a complex with positively charged ions such as  $\text{Ca}^{2+}$  as well as  $\text{Mg}^{2+}$  and in this way as much as 20–25% of the phosphates can be inactivated.

The introduction of water into a meat product, besides its technological functions, is important economically as water is still in most countries by far the cheapest ingredient and therefore it plays an important part in the cost structure of a meat product.

**Table 6.3** Values of total hardness for various categories (degrees of hardness) of soft and hard water

Degree of hardness	Total hardness (mg of CaO per l of $\text{H}_2\text{O}$ )
Very soft water	0–40
Soft water	40–80
Slightly hard water	80–120
Medium hard water	120–180
Hard water	180–280
Very hard water	Above 280

From a technological point of view, in order to dissolve protein the presence of water is required to act as a solvent in conjunction with phosphates and salt on muscular protein. Countless meat products become more juicy and succulent through the addition of water. During the manufacture of several meat products, cold water (or ice) is utilized to maintain a low temperature during processes such as cutting and mixing because the activation of muscular protein is most effective at low temperatures. Low temperatures during various processing steps also reduce the risk of bacterial growth.

The water used in meat products must be of drinking quality (potable) and the amount of chlorine within water should be low. Enhanced levels of chlorine react with nitrite present in cured meat products and a significant amount of nitrite could be lost, which would not be available any longer for the formation of curing colour. As a result, highly chlorinated water is not suitable for the preparation of brines containing nitrite as elevated levels of chlorine would come into direct contact with nitrite, causing chemical reactions between those two substances. Highly chlorinated water can also result in a slight chlorine taste in a meat product, which is not desired. Water, depending on its source, can contain increased levels of nitrite and especially nitrate which can lead to the unwanted formation of the pink curing colour in non-cured meat products where no nitrite, or nitrate, was introduced into the product as part of the recipe in first place. The introduction of only 3–4 ppm of nitrite per kilogram of meat product is sufficient to create a touch of pink colour. It is not advantageous to use demineralized water rather than normal water and, in most countries, demineralized water could not be used anyway, given the fact that it is not classified as food.

## 6.8 Spices and spice extracts

Spices are plants or parts of plants, which are added to food for their contribution towards flavour, aroma and taste. They are not added for nutritional purposes as they do not supply energy and are consumed in very small quantities. Around 50% of the spices produced in the world are used in the meat-processing industry and all spices used in meat products are of premium quality. Second-grade quality spices are generally bought by consumers in the supermarket. Besides the four basic tastes (bitter, salty, sour and sweet), aroma is experienced by the mucous membrane within the nose and over 5000 different aromas can be distinguished.

Spices have an impact on the flavour and appearance of a product as well as its taste. Some spices also aid digestion and increase appetite overall, some, such as rosemary, sage and their extracts, have antioxidative properties, while others, such as thyme and garlic, have bacteriostatic properties. The bacteriostatic properties of garlic and thyme, however, cannot be exploited to the full in meat products, as the inclusion level required for a satisfactory bacteriostatic effect would not be tolerated by the consumer from an

organoleptic point of view. In total, around 60 spices demonstrate bacteriostatic properties to some degree.

Most spices used are dried, frozen or preserved in brine. Spices should be stored under cold or ambient temperatures and the storage area should be dry. The RH in the storage area should not exceed 65% and if stored too warm, aroma components in the spices vaporize and are lost. Stored under high humidity, mould can grow and if stored unprotected against the impact of light, colour can fade and atypical aromas can develop. Once a bag of spice is opened, it is vital to close the bag properly afterwards as volatile oils and other aroma compounds will evaporate. Storage in moisture and air-proof containers or aluminium bags is an advantage. Spices can be highly contaminated with pathogens and spores and, when purchasing spices, the specification should show figures regarding the total plate count (TPC), the *Salmonella* spp., *E. coli* and *Listeria* spp. count and so forth.

Spices originate from roots, barks, leaves, herbs, blossoms, seeds or fruits of certain plants. The different types of flavour originate commonly from various alcohols, aldehydes, esters, lactones and ketones. Spices also contain water, salts and low-molecular-weight substances such as sugar, fatty acids and amino acids. They also contain high-molecular-weight substances such as lignin, cellulose and starch. Depending on the type of spice, they also contain volatile oils, and bitter, spicy and colour components. The level of essential oil in spices varies from 0.01% to 16%; most spices contain on average around 1%. The level of extracts in spices varies greatly and is between 0.1% and 24%, with most spices containing extracts at an average level of between 2% and 5%. Most spice blends in meat products are applied at a level of 3–6 g per kilogram of product based on a spice blend containing 100% spices. However, spice blends are frequently a mix consisting of natural spices as well as some extracts. Spice blends based on extracts only are added at a very low level per kilogram of meat product. Commonly, spice blends contain filler materials such as sugars and salt, and strict guidelines are in place regarding the terms used to describe spice blends containing different levels of non-spice components. For example, in most countries, a product sold as a spice blend can contain non-spice materials such as carriers in the form of sugar or salt up to a maximum level of 5% without having to declare the filler materials.

Different parts of plants are the origin for spices and herbs.

- 1 Seeds such as mustard, coriander, cardamom and nutmeg.
- 2 Fruits such as pepper, paprika, caraway and pimento.
- 3 Leaves and herbs such as marjoram, rosemary, oregano, mint, sage and thyme.
- 4 Spices from blossoms, parts of blossoms or buds such as saffron and clove.
- 5 Roots and rhizomes such as ginger, turmeric and horseradish.
- 6 Bark spices such as cinnamon and cassia.
- 7 Bulb spices such as onion and garlic.

Hot flavours are obtained from chilli, mustard and pepper whilst pungent flavours are found in spices such as anise, cardamom and cloves. Sweet flavours are present in allspice, cinnamon and vanilla whilst tangy flavours are seen in ginger and sumac. Amalgamating flavours are present in fennel and coriander seed. The spicy-hot component in spices such as chilli, belonging to the capsicum annum spices, is capsaicin whilst the non-spicy pepper flavour is based on piperine. For chillies, as rule of thumb, the smaller the chilli, the more heat is in it. Capsaicin is present primarily in the seed of a chilli as well as inside the chilli wall and is around 300 times more spicy hot than piperine. Chilli contains up to 0.7% capsaicin and the level of heat in spices is generally expressed in Scoville heat units.

Spices such as onions and garlic only develop their characteristic and pronounced flavour, once cell walls are destroyed through cutting or chewing because an enzyme, present in those spices or fruits, has to come in contact with other intrinsic substances to produce the flavour. If a small onion were swallowed as a whole, no onion flavour would be created as the enzyme would not have the chance to react with other substances in order to form the actual onion flavour. The same applies to garlic. In the past it was believed that the crying sensation by cutting onions was caused by the enzyme allinase. It is known today that allinase plays only a minor role, the major cause being an enzyme known as lachrymatory factor synthase. Once an onion is cut and cell walls are destroyed, lachrymatory factor synthase is released into the air and converts the amino acids present in onions, such as sulphoxide, into sulphenic acid. Sulphenic acid, which is an unstable substance, turns into syn-propanethiol-S-oxide which, once in contact with air, irritates the lachrymal glands causing the production of tears. Because of their pyruvic acid content, onions can cause browning in meat products and it is the pyruvic acid which is also responsible for the pungency of onions. The acid acts also as an oxidizing agent, and enzyme activity also plays a role in discolouration in meat products based on the presence of onion. The problem can occur from fresh, dried or even frozen onions but, if onions are heat treated first, the problem is reduced. As do onion and garlic, chives also belong to the allium family (allium = onion plants). Onion, or *Allium cepa*, exhibits only around 180 g of essential oil per 1000 kg of fresh material whilst garlic produces around 2.5 kg of essential oil per 1000 kg of fresh material. Garlic, or *Allium sativum*, contains up to 25% of sugar whilst onion contains around 10% of sugar. Different levels of sugar play a vital role within the browning of those materials upon heat treatment during the Maillard reaction. The predominant aroma component in garlic is allicin.

Pepper is used in the forms of white, black, green and pink pepper. Black peppercorns are the green and unripe peppercorns picked from the vine and dried in the sun. Upon drying in the sun, the outer husk turns from green into black and the volatile oil piperine is formed during this process, which gives black pepper its characteristic flavour. White pepper is obtained by soaking the almost ripe peppercorn in water and subsequent removal of the outer

husk before finally being dried. White pepper is 'hotter' than black pepper but the piperine taste in white pepper is significantly less pronounced than in black pepper. Green peppercorns are picked green and placed either in a salt brine or freeze dried to prevent an enzymatic reaction, which would turn the green into a black corn. Pink pepper is the ripe berries put into a salt brine in order to avoid any enzymatic reaction. Pink pepper has a fruity note and underlying heat.

Real vanilla is very expensive and therefore vanillin is commonly used instead. Vanilla is obtained by drying and curing the tasteless and green pod from a tropical orchid native to South America. Vanilla contains around 1.5–3% of actual vanillin and 0.15–0.3% hydroxybenzaldehyde as its characterizing flavour component. This ratio of vanillin to hydroxybenzaldehyde must be 10:1 and based on this ratio, the addition of synthetic vanillin to vanilla can be detected. Vanillin can also be made chemically and is not a spice but tastes very similar to vanilla.

It is carotenoids that give paprika its red and yellow colour. Carotenoids are soluble in fat and, if used excessively, they can give the fat portion in a sausage a yellow appearance. Excess use of oleoresins from paprika also results in a touch of yellow colour in sausages. Spices and herbs can also be a source of nitrite as well as nitrate, which can cause pinking of meat products where no pinking is desired.

The level of microbiological contamination in untreated spices varies considerably. Country of origin, harvesting methods applied, hygiene during transport and other parameters determine the level of contamination and the bacteria count in black pepper can be as high as  $10^8$  cfu/g. Treatment of spices with different materials such as ethylene oxide is common in order to reduce the bacteria count but an increasing number of countries do not permit the use of ethylene oxide any longer. Steam treatment is frequently applied as an alternative to reduce the bacteria count but is much less effective as treatment with ethylene oxide. Most leaves and herbs cannot be treated with steam at all, however, because appearance and taste changes dramatically. Generally, steam-treated spices and herbs should demonstrate a TPC of less than  $10^5$ /g, less than  $(1-3) \times 10^3$  on yeasts and moulds and less than 50 of *E. coli* per gram. *Salmonella* spp. should be not detected in 25 g.

The microcount of spices and herbs is critical towards the intended application of spices in meat products. Meat products, which do not undergo heat treatment during manufacture, such as raw fermented salami, fresh sausage or marinated meats, should be produced by utilizing either treated spices, untreated spices presenting a low bacteria count or spice extracts. Such microbiologically sensitive products should not be produced using untreated spices showing a high initial bacteria count, as a faulty product and a greatly reduced shelf life would be the result. The selection of such low-bacteria-count spices is not that critical in meat products which are fully cooked during manufacture. Other options for a reduction in microcount would be the treatment of spices with chlorine, UV light, irradiation,

formaldehyde, hydrogen peroxide or high pressure. Most of those treatments did not make a successful transformation into the commercial world or are not permitted.

Different spices demonstrate different stability against heat. Heat-stable spices are sage and chillies, whereas less heat-stable spices are rosemary, thyme, cardamom, paprika, clove and pepper, and also other spices such as coriander, pimento, mace, marjoram and ginger are not heat stable. The lower stability towards heat is compensated through a higher addition rate to meat products during processing.

Spice oleoresins or extracts consist of essential oils, soluble resins and other materials present in the original spice as well as non-volatile fatty acids. An oleoresin or extract is basically the 'total flavour of a spice in a concentrated form', obtained via extraction initially and treatment with solvents afterwards. Solvents commonly applied are alcohols as well as ether, and extracts do not contain cellulose or starch, which makes those materials almost sterile.

Essential oils are the principal or specific flavouring component of spices mostly obtained via steam distillation from the original spice. The major part of a spice, whether it is a fruit, the bark, a seed or any other part, does not contribute much to the flavour given that those parts are predominantly made out of fibrous tissue and water. Only paprika, sesame seed and cayenne pepper have a flavour on their own and the content in essential oil is not of significant importance towards their flavour. Liquid-soluble spice flavourings are commonly blends of oleoresins as well as essential oils and diluted to a specific strength by the addition of a solvent such as glycerol. Oleoresins and essential oils demonstrate the advantage of exhibiting a standardized and uniform flavour, are low in bacteria count and also demonstrate a long shelf life. Flavour development within meat products by applying oleoresins takes place more quickly than with the use of natural spices, and full flavour strength is obtained immediately. When utilizing natural spices, it takes around 12–24 h until the full flavour strength in a meat product is developed but the flavour lasts longer within the product if natural spices rather than oleoresins are used. Therefore, the evaluation of the flavour and taste of a meat product such as frankfurters, produced with natural spices, should take place once the product is at least 1 day old.

## **6.9 Hydrolysed vegetable protein**

Hydrolysed vegetable protein (HVP) is applied worldwide for flavouring meat products. The main sources for HVP are soy, maize or gluten, and soy is the preferred source for meat-flavoured HVP. During the manufacture of HVP, plants such as soy are broken down into their individual components such as amino acids and other peptides with the help of acids, mostly hydrochloric acid. Hydrochloric acid is afterwards neutralized with an alkali such as sodium hydroxide, and salt, water and sodium salts of amino acids

are obtained. The resulting slurry is called HVP and is subsequently exposed to heat treatment, which causes different amino acids to react with each other. New and different flavours are the result of reactions under the impact of heat and HVP is quite cheap compared with other flavours.

When plants are broken down into their individual components (amino acids) with the help of acids such as hydrochloric acid, however, the chloride ions from those acids react with lipids found in those plants (the lipids are found in trace amounts only). A reaction between chloride and lipids creates 3-monochloropropane-1,2-diol (3-MCPD) and this substance has been shown to be carcinogenic in laboratory animal studies. Once formed, the stability of 3-MCPD depends on the pH value and temperature to which it is exposed. High temperatures as well as increased pH-values in meat products accelerate the degradation of 3-MCPD. As a consequence, it is a common trend currently in certain countries that manufacturers of meat products are using more often flavours and flavourings based on yeast extracts, which are free of MCPD.

## 6.10 Antioxidants

Antioxidants must work in low concentration such as 200–500 ppm per kilogram of meat product, should demonstrate good solubility in fat or fatty material, must be non-toxic and also must not change or alter the taste of the meat product itself. Antioxidants in meat products have the primary task of deactivating or neutralizing free radicals to slow down the development of rancidity. More specifically, antioxidants extend the period of time until a significant number of oxidation-related substances are formed and rancidity is observed. Deactivating peroxides is a secondary function of antioxidants and of far less importance. Antioxidants can block radicals, which are substances with a lone pair of electrons and therefore ‘negatively’ charged (see Chapter 1, Section 1.9), by donating hydrogen atoms, and stabilize such radicals. Most antioxidants become radicals themselves by donating hydrogen atoms but are significantly less reactive and quite stable compared with radicals obtained from autoxidation. As a result of deactivating radicals, less hydrogen peroxide is formed, which can react to form substances such as aldehydes as well as ketones and therefore contribute to the rancid flavour and taste. Ascorbic acid also acts as an oxygen scavenger at the same time and therefore deactivates oxygen which is otherwise utilized, firstly, for the formation of peroxide and, secondly, for breaking bonds on double linkages in unsaturated fatty acids, leading to the formation of radicals.

Phenolic substances such as tocopherol, carnosic acid and rosmarinic acid and phenols from smoke (all cyclic unsaturated systems) can also deactivate radicals as well as hydroperoxides by either donating hydrogen (phenols are weak acids) or by neutralizing them by absorbing radicals into their ring-shaped molecule. When a phenol donates hydrogen in order to neutralize hydroperoxide, the phenol is oxidized to a phenol radical which can be

reduced again by gaining hydrogen. The donor of the hydrogen can be ascorbic acid and the phenol radical is reduced again to phenol. Ascorbic acid can donate two hydrogen atoms and is therefore a very active donor to phenol radicals, which is the primary function of ascorbic acid as an antioxidant. The newly-formed ascorbic acid radical is quite stable despite the removal of hydrogen. Within such a system, ascorbic acid acts as an indirect antioxidant. On the other hand, phenols can absorb radicals into their ring-shaped molecule and the configuration of the ring does not change within the process. The absorbed radical is bound, or neutralized, within the ring by moving the radical around inside the ring but not being bound to a specific atom.

Ascorbate, the salt of ascorbic acid, as well as ascorbic acid itself, is insoluble in fat and shows very little antioxidizing effect in fat. Materials such as ascorbate, or erythorbate, are commonly present in a ham brine. Erythorbate and erythorbic acid are optical isomers of ascorbate and ascorbic acid. Erythorbate and erythorbic acid show the same chemical properties as ascorbate or ascorbic acid but have no vitamin character. Once introduced into meat, which has a slightly sour pH value by nature, some undissociated ascorbic or erythorbic acid is obtained and those compounds can also donate hydrogen in order to block radicals. More effective antioxidants on fat would be tocopherol, butylated hydroxyanisole (BHA) or BHT, which are all phenolic substances.

Tocopherols are a group of four out of eight naturally occurring compounds, which are fat-soluble vitamins known collectively as vitamin E. The position of the methyl group within their ring structure makes the difference within those four compounds, which are known as  $\alpha$ -,  $\beta$ -,  $\gamma$ -, and  $\delta$ -tocopherol. In meat and meat products,  $\alpha$ -tocopherol is predominantly utilized because it is significantly less expensive than  $\gamma$ - and  $\delta$ -tocopherol. However, the antioxidative properties shown by  $\alpha$ -tocopherol in meat products are very limited whilst  $\gamma$ - and  $\delta$ -tocopherol exhibit much stronger antioxidative properties. Commonly, a mix of  $\gamma$ - and  $\delta$ -tocopherol in a ratio of 1:1 is applied, which shows a synergistic effect as an antioxidant. Antioxidative properties of tocopherols are contrary to their vitamin character given that  $\alpha$ -tocopherol demonstrates the strongest vitamin character but is the weakest antioxidant within the tocopherol group. However, other opinions suggest that  $\alpha$ -tocopherol is the only tocopherol with significant biological activity. Tocopherols deactivate free radicals in fats as tocopherols are fat soluble and therefore delay rancidity in meat systems containing fat. At the same time, tocopherols are insoluble in water and cannot be used in ham brines. The usage rate of tocopherol is around 0.02–0.05% or 0.2–0.5 g per kilogram of finished product. Excessive levels of tocopherol reverse the antioxidative function and the antioxidant acts in a pro-oxidative way and will speed up rancidity.

Polyphenols in green tea oil such as catechine (epigallocatechin gallate) are stronger antioxidants, e.g. vitamins A, C and E, but are very expensive and leave a green tint in meat products. Rosemary and oregano contain phenolic substances such as carnosic acid. Carnosic acid donates hydrogen to neutralize a free radical and turns into carnosol, which is itself an antioxidant, by

deactivating free radicals. Rosmanol, another antioxidant, is formed from carnosol in the next step and then another antioxidant galdosol is obtained from rosmanol. This chain reaction explains why carnosic acid acts as an antioxidant in many different ways and substances such as rosmanol and carnosol demonstrate only around 40% antioxidative properties compared with carnosic acid. Rosemary and oregano extracts are already very effective at usage levels of 0.05–0.08 g per kilogram of finished product and oregano extract has an even stronger antioxidative impact than rosemary extract. Those phenolic compounds also have an impact on other Gram-positive bacteria as well as on *Listeria monocytogenes*.

Sage demonstrates an antioxidative impact as well, and both rosemary and sage can delay the period of time until fat-containing meat products exhibit rancidity by around 14 times. Rosemary and sage contain around 0.3% of carnosic acid, which surpasses tocopherol as well as BHT in their functionality. Carnosic acid is in most countries not permitted as a direct food additive but is present in rosemary, sage and oregano extract. Those phenolic substances, as stated above, either absorb radicals into their ring-shaped molecule or donate hydrogen in order to stabilize free radicals. Synthetically made phenolic antioxidants such as BHT and BHA are very similar to each other and not permitted in quite a few countries. BHA is a mixture of two isomers where one of them, 2-BHA, is present at around 82–85% and the other, 3-BHA, at around 15–18%. BHT or BHA is rarely applied in meat products; if so, use is made in products such as sausages and meatballs and the usage rate is commonly 0.01% based on the fat content as a single antioxidant or 0.02% if both are applied in combination. Today, BHT and BHA are under suspicion of causing cancer.

Heavy-metal ions contribute to and speed up oxidation. Citric acid can form a complex with heavy-metal ions (it is a chelating agent) and heavy-metal ions lose their supporting potential to oxidize fat. In animal fat itself, heavy-metal ions are rarely present but in a finely comminuted sausage, such as a hot dog, heavy-metal ions coming from meat are finally present in the sausage mass and the presence of citric acid is a 'solution' but depends heavily on the amount of citric acid added. The addition of an acid is meaningful from an antioxidative point of view but not from a technological point of view as the addition of an acid can cause (depending on the amount added) a decline in pH value within the meat product and a decrease in WBC. The impact of substances such as phosphates acting as chelating agents is much greater than the impact of citric acid. This is because phosphates are added to meat products at a significantly higher level per kilogram of meat product and this is why citric acid is generally not utilized as a chelating agent.

## 6.11 Natural smoke

Smoke has been applied for around 80 000 years in the production of meat products and is produced by incomplete combustion (pyrolysis) of wood

material such as sawdust or woodchips. Friction or steam condensation are two other methods of generating smoke. In the friction method, a piece of wood of a certain size is pressed against a fast running rotor with a ripped surface and high frictional forces are the result. Friction smoke is obtained, which exhibits a high level of phenols, carbonyls and other acids whilst showing a low level of tar and polycyclic aromatic hydrocarbons (PAHs). Pyrolysis takes place through the heat obtained during friction between the piece of wood and the rapidly rotating rotor with the ripped surface. Steam smoke is obtained by the use of overheated low-pressure steam and the temperature within this process is between 300 and 450 °C. A spirally shaped element transports sawdust into an area where such overheated steam is applied on to sawdust or wood-chips, causing pyrolysis. The generated smoke is cooled to around 85 °C until it reaches the smoking chamber which causes an increase in moisture (RH) within the smoke and this gives the basis for the name 'steam smoke'. Steam smoke is basically free of tar as well as PAHs.

Wood consists of around 50% cellulose, 25% hemicellulose and 25% lignin. From those materials, around 50–70% turn via pyrolysis into smoke and pyrolysis results in burnable coal rather than ash by burning wood slowly at a certain temperature. The term hemicellulose describes polysaccharides which are made from different pentoses and hexoses. Hexoses are monosaccharides containing six carbon atoms whilst pentoses contain five carbon atoms within their molecule. Pyrolysis takes place in four steps.

- 1 Drying of the wood up to around 160 °C.
- 2 Pyrolysis of the hemicellulose between 180 and 250 °C.
- 3 Pyrolysis of the cellulose between 250 and 300 °C
- 4 Pyrolysis of the lignin between 300 and 550 °C.

The optimal temperature for combustion is between 350 and 500 °C and temperatures below or above this range cause a considerably higher amount of unwanted substances within smoke afterwards. The most well-known and dangerous of those unwanted substances is 3,4-benzopyrene, which is carcinogenic and belongs to the group of PAHs. If smoke is generated at temperatures between 350 and 500 °C, PAH contamination is greatly reduced and concentrations of less than 1 ppb per kilogram of smoked meat product are obtained.

Smoke is a highly complex mixture of gas-like substances, solid particles (particulate phase) and water, and around 600 components within smoke are known today. The particulate phase accounts for around 80% whilst the gaseous phase for around 20%; the gas fraction is not visible to the human eye and is yet very complex. The composition of smoke depends primarily on the type and moisture content of wood utilized as well as on the method used to generate smoke. The main components of smoke, having the largest impact on meat products, are phenols, organic acids and carbonyls. Most of those substances are in the gaseous phase and not in the particulate phase.

Phenols are not, as one might think, alcohols but acids (carbolic acid) and are obtained through the pyrolysis of lignin by a temperature between 300 and 450 °C. Phenols can release a proton from a hydroxyl group and that makes them a weak acid. The visible particle fraction consists of small liquid colloidal smoke particles. Those particles are very small in size, around 1 µm, and are distributed within the gas fraction. Much larger particles such as ash and tar are also part of the visible particle fraction. Two phenolic substances coming from lignin, namely syringol or guaiacol (2-methoxyphenol), are of importance towards the smoke colour and flavour in meat products. Guaiacol results from the lignin present in soft wood and is not favoured as it gives it gives a dark dull smoke colour as well as a rough and unpleasant smoke taste. The desired golden-brown smoke colour, as well as pleasant smoke flavour, originates from syringol, which is obtained from lignin present in hardwood such as oak and hickory.

Wood chips or sawdust should be stored in a dry area and no animals should have access to this area. It happens quite often that woodchips are contaminated with animal faeces and/or urine. Sawdust or woodchips have to be moistened first with water; otherwise the wood material becomes too hot very quickly (above 450 °C) and little smoke is obtained. The amount of water added to the wood material is around 20–30% of the weight of the wood material. Also, the smoking chambers must not be overloaded during the application of smoke in order to avoid hot spots. Air still has to move freely within the smoking chamber in order to achieve an even drying, smoking and cooking impact.

Table 6.4 shows the three different methods of smoking.

The main functions of smoke are described in the following sections.

#### *Development of the smoke colour*

Smoking of meat and meat products results in a nice and appealing golden-brown colour, which is very attractive to the human eye. Carbonyls are the main colour-forming agents and carbonyl is absorbed into the slightly moist surface of the product. Subsequently, carbonyls react with amine to form the desired smoke colour. To a small degree, phenols also contribute to smoke colour. It is important to have the correct level of moisture on the surface of the meat and meat products in order to obtain a nice smoking colour. Evenly dried products result in a very appealing smoke colour and a dry surface absorbs significantly less smoke (as well as ash and tar) than a wet surface. If the surface is too wet (underdried), a brownish colour and even streaking

**Table 6.4** Different methods of smoking

Method	Temperature (°C)	RH (%)
Cold smoke	15–25	50–85
Warm smoke	25–50	50–80
Hot smoke	50–90	30–85

(tiger stripes) can be the result of smoke absorbed unevenly on products such as frankfurters. Streaking occurs when there is some free moisture on the surface of the product. When the surface is overdried, a lighter than wanted colour is obtained. Hence, moderate levels of moisture must be present within the smoking chamber during the smoking process as such to obtain an even smoke colour. Uneven smoke colour is also commonly the result of not having achieved the same conditions regarding surface moisture and temperature of the product to be smoked inside the smoking chamber prior to smoking. In this case it might be necessary to 'condition' products such as frankfurters by showering all for a short while in order to obtain the same level of moisture and surface temperature.

Filling of large smoking chambers with trollies of frankfurters can take a while and the product going into the smoking chamber first can exhibit a dry surface, compared with a wet surface from the last products until the chamber is finally full. Basically, the surface of the product to be smoked should be slightly tacky before smoke is applied. For sausages such as hot dogs which are filled into natural casings, the casing should feel like human skin after drying prior to the application of smoke.

If a dark, or black, smoke colour is wanted on the meat product, a high level of humidity is required within the smoking chamber and the drying phase must be short or not part of the smoking process at all. Prolonged periods of smoking commencing on a wet product surface without prior drying produce such a dark and almost black colour because a wet surface demonstrates high smoke absorption. Some of those dark-coloured meat products are called pit smoked. High levels of moisture, around 80–85%, are also maintained during the smoking process to obtain such a dark colour. To fixate the dark colour, some of those wet-smoked products are finished off with hot air (baked) and such treatment enhances the darkness of the product in comparison with being finally steam cooked. Generally, the smoking chamber must not be overloaded with products, in order to secure an even airflow and thus an even distribution of smoke and humidity within the chamber. In order to even out the smoke colour, short drying steps of 3–5 min are commonly introduced between smoking cycles for products such as hot dogs or frankfurters.

#### *Development of the smoke flavour*

It is a well-known fact that smoked meat products taste differently from non-smoked products. Substances such as formaldehydes, lactones and up to 20 different phenols (guaiacol and syringol) are primarily responsible for the smoke flavour. Hardwood such as maple, oak, beech, hickory and mahogany is preferred because these types of wood give a clean and non-tar flavour.

#### *Smoke as preservative*

Smoked meats and meat products last longer, a well-known fact for thousands of years. Formaldehyde, phenols and acetic acid are the main agents for

extending shelf life of smoked products as these are very effective antimicrobial substances. Phenols are acids which denature proteins and disrupt cell membranes. Disrupted cell membranes eventually kill the cell or make it very hard for the cell to survive or even to grow.

#### *Smoke adding to bite*

Smoked sausages such as frankfurters obtain a much better bite, or snap, through smoking. Components of smoke, mainly formaldehyde and other organic acids, combine with the activated protein on the surface of the non-cooked sausage and subsequent thermal treatment creates a firm layer around the sausage, which is largely responsible for the snap. Smoke contains around 0.6–1.0% formaldehyde.

#### *Mistakes during smoking*

The most common mistakes during smoking are as follows.

- 1 An uneven smoke colour is obtained owing to faulty equipment and insufficient smoke distribution within the smoking chamber. Insufficient and/or uneven drying of the product to be smoked is commonly a reason for uneven smoke colour as the remaining amount of moisture on the surface interferes with the absorption and incorporation of smoke into the surface. The product can be spotty, exhibiting tiger stripes, and the colour will be dull overall.
- 2 Overloading of the smoking chamber leads to uneven airflow and also can cause uneven smoke colour.
- 3 A negative impact on the flavour can be seen by using mouldy sawdust or chips. Hence, sawdust or chips must be free of wood impregnation substances and urine from animals.
- 4 Overdrying of the product leads to toughening of the casing and natural casings lose their ability to stretch and shrink. As a result, wrinkles are obtained and the product also loses its shine.
- 5 If smoked too long, the product can acquire a slightly bitter taste and a wrinkly product is often the result as well.
- 6 Quite often, smoking time is prolonged when the surface of the product was insufficiently dried and an uneven formation of colour is seen. A spotty and uneven smoke colour is the result. By using modern smoke chambers today, the actual time of smoking should not exceed 15–20 min for sausages such as frankfurters.

## **6.12 Liquid smoke**

Liquid smoke is produced by burning selected woods under controlled conditions. The smoke obtained is condensed on water and recycled until the desired concentration is given. Liquid smoke can be applied on to meat

products via atomization, a dipping or shower system, brine addition to meat products and in the form of smoke-impregnated casings. Atomization is the spraying of liquid smoke under a predetermined pressure through a nozzle into the smoking chamber and creating a cloud of smoke made from very tiny particles.

Before liquid smoke is introduced into the smoking chamber, the meat product first has to be dried properly. After atomization, the cloud of smoke is allowed to dwell for around 10–15 min within the chamber before a drying step of 5–10 min is introduced. The spraying process can be repeated several times until the desired smoke colour is obtained and two or three applications of spraying results in a nice golden-brown colour.

Within a shower or dipping system, products such as frankfurters are showered with or dipped into a liquid smoke solution for a short time. The dipped or showered products are dried afterwards to fixate the smoke on to the surface before being thermally heat treated afterwards, primarily by the application of steam. Processes such as dipping or showering, colour fixation and thermal heat treatment of products such as frankfurters run continuously in large-scale operations.

Following a new development, meat products of all types can now be smoked with a specifically developed type of liquid smoke, and a fine mist of smoke can be directly applied to the products without a drying step prior to smoking. Smoking trolleys filled with products are showered with a fine mist of smoke for around 2 min and within this period of time the product acquires a nice golden-brown colour. The next step is a short drying step in order to fixate the colour followed by the actual cooking process. Therefore smoking and heat treatment can start much earlier and the entire smoking and cooking process is shortened by up to 50%.

Commonly, meat products which should exhibit smoke flavour without being smoked experience the addition of smoke, either in the form of a powdered smoke flavour or liquid smoke, directly into the product. For example, hams which are filled into waterproof casings exhibit a touch of smoke flavour as the flavour was introduced into the injection brine or into the brine, which was added to smaller minced pieces of meat in the first place. Casings are also available with a layer of smoke on the inside. Such casings are generally not soaked before filling as such treatment with water during soaking would wash out the layer of smoke. The filled products, primarily ham products, are filled into the casing and a 1 h period of drying by low humidity and temperatures around 70–75 °C is commonly the first step to fixate the colour on the meat product before being finally cooked by the application of water or steam.

In the past, liquid smoke commonly produced a slightly bitter taste on meat products but, because of ongoing improvements on the quality of liquid smoke, this negative side effect belongs to the past.

Liquid smoke shows several advantages compared with natural smoke.

- 1 Because liquid smoke is 'standardized', an even smoke colour on the finished products can be obtained all the time.
- 2 There is no emission of smoke into the air and therefore smoking with liquid smoke is environmentally friendly.
- 3 Smoke chambers are easy to clean as liquid smoke does not contain tar and other tacky substances. Most of the time, the smoking chambers can be cleaned with water only and no chemical cleaning detergent is required.
- 4 Liquid smoke is almost free of PAHs.

### 6.13 Colours in meat products

Quite a large number of colours are permitted to be applied in food overall but only a few are suitable for meat products. Colours which restore or enhance the red curing colour are utilized and the acceptance of colours in meat products varies from country to country.

Within the EU and other countries, the maximum level of colour permitted in a meat product is not specifically defined but expressed with the Latin term *quantum satis*, meaning 'as much as needed'.

Colours can be divided into three major groups.

- 1 Natural colours from plants or animals such as carotene, cochineal, beet red, curcumin (orange–yellow colour derived from the rhizome of turmeric) and paprika extract.
- 2 Colours derived from natural sources such as caramel and titanium dioxide, a white pigment.
- 3 Artificial colours such as tartrazine, Ponceau 4R and Red 2G.

The most commonly applied colours in meat products are discussed in the following sections.

#### *Carmine of cochineal (E 120)*

Carmine is the red colour which accumulates in the shell of pregnant scale insects (*Dactilopius coccus*). A liquid extract is obtained from such dried female insects and then mixed with alumina to produce the alumina solution of carminic acid which is the main colouring agent in carmine. Since the alumina solution of carminic acid is not water soluble, it must first undergo treatment with material such as ammonia or carbonate (alkalis) so that it becomes soluble in water. Cochineal dissolves well in water and is applied widely in cooked hams and cooked sausages. As cochineal is not soluble in fat, the colour is well suited to salami and ham with fat and skin on as it provides colour to the meat only and does not discolour fat at the same time. A colouring effect in a meat product can be observed when adding as little as 0.02 g of cochineal per kilogram of meat product and the colouring is quite stable against light, pH variations and thermal treatment.

*Ponceau 4R (E 124)*

Ponceau 4R is a synthetically made colour nowadays but in the past was made from coal tar. Ponceau 4R cannot be applied at the same time as SMBS in products such as fresh sausages as it reacts with SMBS, causing the formation of green and yellow colour in such meat products.

*Caramel (E 150)*

Caramel is a nature-identical colour and is dark brown, being frequently utilized to give a dark appearance to the surface of meat products such as roast beef but also sometimes added to emulsion-type products such as frankfurters. Caramel is produced by controlled heat treatment of glucose syrup in conjunction with alkali or sulphur dioxide in order to enhance caramelization.

*Beet red (betanin) (E 162)*

It is the extract of beetroot and of purple-red colour. The main colouring agent is  $\beta$ -D-glucopyranoside of betanidine (betanin) but beet red shows poor stability against the impact of light and heat.

*Fermented rice*

Fermented rice (angkak) is of rice origin and a dark-red powder. It is in most countries not classified and also not permitted as a colour whilst other countries classify fermented rice as food and as such it can be used in meat products. The main reason for the different classification of fermented rice, and as such either being permitted or not, is that the mycotoxin citritin is present in fermented rice and citrinin is known to cause cancer. Fermented rice is applied for colouring purposes and is made out of a natural pigment present in mushrooms such as *Monascus purpureus* and *M. angkak*, which grow on moist rice. Such azaphilone pigments are ultimately extracted from *Monascus* spp. Most types of fermented rice start to show an impact on the colour of a meat product when applied at 0.1 g per kilogram of product. Fermented rice is stable against light and heat.

*Allura red (E 129)*

Allura red is an artificial dye and applied commonly in combination with red wine powder and/or Ponceau (E 124).

*Paprika oleoresin*

Paprika oleoresin is widely utilized for sausages if a paprika-red colour is wanted. The oleoresin is not a colour *per se* but the main reason for being introduced is the colour-giving effect on sausages. Several types, or qualities, of paprika oleoresins are available and the concentrations vary from 20 000 to 100 000 colour units (CU). Generally, the better the quality of the oleoresin, the longer the colour lasts in the meat products. The colour obtained from paprika oleoresin in products such as fresh sausages is not stable and over

time, especially in combination with high storage temperatures of the product, the colour starts to fade until it has totally disappeared.

Excess amounts of paprika oleoresin added to a cooked sausage result in a slight touch of yellow in the cooked product. It is a common problem for sausage premixes containing paprika oleoresin, which are sold to tropical and subtropical countries where the sausage premix quite often is stored in a warehouse under hot conditions over several months, that fading of the paprika colour can be seen within a relatively short time within the premix. Fading of the paprika colour within the sausage premix, depending on the storage temperature, can occur within 1–2 months but can be delayed by the addition of, for example, rosemary extract to the paprika oleoresin at levels around 0.05%. An appealing and genuine paprika-red colour can be obtained in products such as fresh sausages or burger by adding around 0.1–0.3 g of a 40 000 CU oleoresin per kilogram of product.

#### *Red 2G*

Red 2G is used in fresh sausages. Unlike other colours, Red 2G is not affected by the presence of SMBS and is also stable against the impact of light during storage.

### **6.14 Whitening (bleaching) of meat**

Whitening of meat is primarily an issue in poultry and methods to turn dark chicken meat such as thigh into light-coloured meat have been worked on for countless years. White meat, especially in poultry, enjoys an image of being healthy, easy to digest and generally promoting health. There is no legal way to turn dark meat into white meat by the addition of an additive, and with good reason. It would be impossible afterwards for the consumer to distinguish by eating, for example, a crumbed chicken nugget between a nugget made out of real breast meat or ‘whitened’ dark meat. Titanium dioxide (E 171) is a colour permitted in most countries and is derived from the mineral ilmenite. It is a powerful white colour and is occasionally added to lighten products. Hydrogen peroxide ( $H_2O_2$ ) is in its water-free state a colourless, oily and highly explosive substance. It is a very strong oxidizing agent, destroys colour pigments and therefore would bleach meat. To the knowledge of the author, no country permits the use of  $H_2O_2$  as a bleaching agent in meat. Sulphite and chlorine would bleach meat as well but sulphite would need to be introduced at levels where human health would be definitely at risk and chlorine would, besides being not permitted as a colour, add a non-acceptable flavour to the product.

Within chicken products such as nuggets, sausages and burgers a lighter colour can be achieved by adding milk proteins, starch and chicken skin emulsion to the product. In an emulsion-type product such as frankfurters, the addition of chicken skin emulsion and oil (see Chapter 12, Section 12.2)

creates an almost white product even though thigh and some MDM meat is utilized. The addition of milk also lightens colour but is not common practice and, if done, some of the ice added to sausages is replaced with frozen milk.

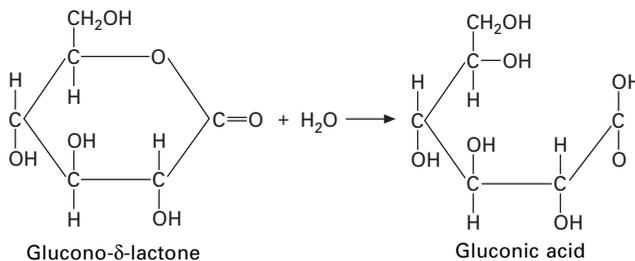
### 6.15 Glucono- $\delta$ -lactone

Glucono- $\delta$ -lactone (GDL) (Fig. 6.12) is a derivate of glucose, i.e. a saccharic acid and is a ring-shaped molecule. GDL exhibits six carbon atoms and an OH group is attached on every carbon atom.

In meat technology, GDL is predominantly utilized as acidity regulator in fermented salamis and occasionally as a colour enhancer (see Chapter 7, Section 7.4). Approximately, 1 g of GDL lowers the pH value within salami by 0.1 pH units. GDL itself is a whitish powder and is not sour. Once in contact with water, from the meat, the ring-shaped molecule opens up and hydrolyses to gluconic acid. This acid causes the decline in pH value within fermented salami and GDL is commonly applied at levels between 3 and 12 g per kilogram of salami (see Chapter 16, Section 16.2.1).

### 6.16 Citric acid

Anhydrous citric acid carries the E number 330 and the chemical formula is  $C_6H_8O_7$ . This food acid is occasionally utilized in the production of salami for acidification purposes. Generally, 1 g of citric acid per kilogram of salami lowers the pH value by around 0.2–0.3 pH units and acidifies a salami therefore around two to three times more strongly than GDL. Citric acid also acts as a chelating agent by binding heavy-metal ions such as copper as well as iron and therefore acts as a secondary antioxidant but its contribution as an antioxidant is marginal. Citric acid is utilized in marinades applied to portioned meats such as pork steaks. The material can be bought in a monohydrate (some moisture within the molecule) or anhydrous form (no water within the molecule). Despite the fact that anhydrous citric acid is not highly hygroscopic, it tends to lumping (caking) if stored at a RH above



**Fig. 6.12** Glucono- $\delta$ -lactone and gluconic acid.

75%. The monohydrate material tends to even more to lumping because of the higher internal level of moisture. Both materials are chemically stable if stored at room temperature at around 20 °C and are non-toxic. Citric acid is a naturally occurring fruit acid and commercially produced by the fermentation of a carbohydrate material. It is a white, odourless and crystal material with a strong acid taste and is freely soluble in water and ethanol. Coated (mostly fat-coated) citric acid is used in products where acidification should be delayed.

## 6.17 Emulsifiers in meat products

Within a dispersion, one substance is finely distributed in another phase. Such dispersion systems consist of the outer, or continuous, phase and an inner dispersion phase. A phase is a macroscopic area of the same density as well as chemical composition. Emulsifiers utilized in meat products help to reduce the risk of fat and water separation, lowering the cooking loss as well improving the texture and firmness of the product. An emulsion is defined as a dispersion of two liquid and non-mixable materials such as liquid fat (oil) and water. On the contrary, a suspension is a system where solid fat (and not liquid) is dispersed in a liquid phase such as water. A real emulsion is therefore a liquid–liquid system whilst a suspension is a solid–liquid system. As an example, a finely emulsified sausage such as a frankfurter is a suspension if pork fat (solid fat) is processed and the solid (even so finely cut) fat is covered in a liquid phase made out of water and dissolved protein in its raw uncooked stage. The same product would be an emulsion if oil (liquid fat) were utilized and dispersed in a liquid outer phase.

Within meat products, a fat-in-water emulsion is generally present and fat represents the inner phase and water the outer, or continuous, phase. In such fat-in-water emulsions, the amount of total fat is less than the total amount of water and the fat is finely distributed within water. On the other hand, an example of a water-in-fat emulsion would be butter and margarine where water is the inner phase and fat is the outer, or continuous, phase. In such a scenario, water is finely distributed in fat. A way of differentiating between an oil-in-water or a water-in-oil emulsion is to determine the minor component within the emulsion itself. Butter contains around 90% fat and therefore only a small amount of water. A water-in-fat emulsion is the result as water is the minor component within the system. An example of a fat-in-water emulsion would be milk, because milk contains largely water and only around 3% fat. Fat is the minor component and water is the outer continuous phase. As a result, this is a fat-in-water emulsion.

Emulsifiers are surface-active materials which reduce the surface tension present between two non-mixable phases or substances, and emulsifiers utilized in the food-industry generally demonstrate a molecular weight of below 1000. Emulsifiers are bipolar materials which exhibit a strong lipophilic or

hydrophobic (fat-loving) group as well as a strong hydrophilic (water-loving) group within their molecule. The hydrophilic group within an emulsifier exhibits an electrically charged polar end whilst the lipophilic group exhibits a non-polar end. As a result, the hydrophilic (polar) components within the molecule penetrate into the water phase (as water is polar as well) whilst the lipophilic components orient themselves towards the fat phase. As a result, surface tension between fat and water is reduced and the non-mixable substances stay homogeneously mixed together for a prolonged period of time.

Emulsifiers are characterized by their hydrophilic–lipophilic balance (HLB) value. The HLB scale has a range from 1 to 20 and describes the ratio of hydrophilic to lipophilic groups within the emulsifier. Numbers from 2 to 9 indicate good solubility in the fat of an emulsifier and such materials are commonly used for a water-in-fat emulsion. Numbers from 12 to 18 indicate an emulsifier which demonstrates good solubility in water and is more suitable for fat-in-water emulsions. Emulsifiers with an HLB of around 7–10 would be perfect for most meat products but most emulsifiers on the market show an HLB of between 4 and 6 and are more lipophilic than hydrophilic. Tweens and Spans are emulsifiers as well but are not permitted in many countries and their HLB is above 10. Every native protein can act as a natural emulsifier because proteins contain amino acids and, as such, can act as an emulsifier. Also proteins from egg and milk are emulsifiers to a certain degree.

Emulsifiers commonly applied in meat products are lecithin and monoglycerides and diglycerides from fatty acids as well as their esters with lactic or citric acid. Monoglycerides and diglycerides consist of the alcohol glycerol and fatty acids such as palmitic, stearic and oleic acid which are bound to glycerol. Monoglycerides exhibit one fatty acid bound to glycerol via an ester-bond and two OH groups, which makes monoglycerides fairly soluble in water. Diglycerides demonstrate two fatty acids bound to glycerol and show only one OH group, reducing their solubility in water. By introducing food acids such as citric or lactic acid on the OH group via an ester reaction, the solubility of monoglycerides and diglycerides is enhanced. In the esters of lactic and citric acid, the acids are connected to glycerol on those spots where no fatty acid is present on the OH groups in the alcohol. Within an emulsifier, the OH groups represent the water-soluble part whilst the acid component represents the fat-soluble part.

Monoglycerides and diglycerides are normally applied at around 3–5 g per kilogram of total meat and fat. Products such as liver sausage are generally produced using emulsifiers. In cooked sausages such as frankfurters, the technological use of an emulsifier is limited because such products are not a real emulsion if produced with solid fat. In most cases, the solid fat of pork or beef is utilized and an emulsifier acts effectively only in a real emulsion where the fat phase is present within the product in liquid form, such as oil. If applied in cooked sausages, monoglycerides and diglycerides as well as esters of monoglycerides and diglycerides formed with citric or lactic acid

sometimes find use. In products such as liver pâté and spreadable liver sausage, mainly monoglycerides and diglycerides are applied. Emulsifiers work well in pasteurized products but are generally not utilized in retorted meat products as their ability to act as an affective emulsifier under high-temperature conditions is very limited.

Lecithin is another emulsifier and consists of glycerol, two fatty acids as well as phosphoric acid and cholin. The two fatty acids are bound via an ester bond to glycerol and the remaining free hydroxyl group of the glycerol is occupied with phosphoric acid connected to the alcohol cholin. The binding of the phosphoric acid to the hydroxyl group of the glycerol as well as to the hydroxyl group of the cholin is an ester bond as well. Because of this configuration, lecithin exhibits water-soluble (hydrophilic) functional groups as well as lipophilic (fat-loving) groups and therefore acts as an emulsifier between the two non-mixable substances fat and water within a meat product.

## 6.18 Alginate for re-formed meat

Alginate, a hydrocolloid, forms a gel in the presence of calcium ions and heat is not required for the formation of the gel. The fact that heat is not required means that alginate can be used in re-formed meat products where a larger piece of raw meat is formed from several smaller pieces of meat. Smaller pieces of lean meat of any type, around 3–5 cm in diameter, can be bound together by mixing such meat with a water–alginate–calcium solution. The level of alginate present in such a solution is between 1.0 and 1.5% and the amount of calcium sulphate is around 80–90% of the level of alginate. Alginate is completely dissolved as the first ingredient in water and some shear is required during this process. Once fully dissolved, the calcium source is added and fully dissolved as well. No salt should be utilized for the preparation of the solution because salt interferes with the formation of gel afterwards. Once the solution is mixed with meat straight afterwards and filled, without air pockets, into casings or moulds, the filled product then has to be placed under chilled conditions of 2–5 °C for around 12–24 h for the setting of the gel to obtain good slice coherency. The amount of solution added to meat depends on the surface area of the meat itself and smaller pieces of meat require more solution than larger pieces of meat do, as smaller pieces exhibit a larger surface area. Generally, all the surface area must be well covered with the alginate–calcium solution. The degree of gel formation depends primarily on the availability of  $\text{Ca}^{2+}$  ions, which is determined by the pH value of the solution and the solubility of calcium within the same solution. Sequestering agents such as polyphosphates delay the formation of a gel and if present in the re-formed meat product, can even cause no gel to be formed.

If instant gel formation is to be avoided, encapsulated calcium chloride can be applied and the forming of gel starts only around 30 min after alginate and calcium come into contact with each other. Another form of adding calcium is the use of calcium sulphate or calcium lactate.

## 6.19 Enzymes for re-formed meat and other meat products

The enzyme transglutaminase (TG) catalyses the link between amino acids found in meat, mainly glutamine and lysine, and binds protein molecules together by forming cross-links between those two amino acids through the formation of covalent bonds. In chemical terms, covalent bonds are formed if atoms share electrons. Covalent bonds are much stronger than other bonds such as hydrogen bonds and cannot be destroyed by physical force or heating. The resulting glutamine-lysine links are common in other foods as well. TG is produced via fermentation, mostly of starch, by bacteria such as *Bacillus subtilis* GT. The function of the enzyme does not depend on the presence of calcium and tolerates pH values between 5 and 8, the optimum being 6–7. The optimum temperature for the enzyme to act is 55 °C. Specific to enzymes, the reaction taking place between glutamine and lysine is determined by temperature and time available for the reaction itself.

TG is utilized within the production of cooked ham and cooked sausages and increases the firmness, bite and texture of such products. In injected ham products, the enzyme is added directly into the injection brine whilst being added directly into the bowl cutter during the initial stage of the cutting process during the production of a cooked sausage. TG is also applied in re-formed raw meat products and experience shows that the inclusion of caseinate is beneficial to binding between the individual raw pieces of meat. Other additives such as phosphates or salt are not required within this binding process.

The two methods of producing raw re-formed meat are described below.

### *Method 1: dry addition*

The portions of meat (such as thin fillets) to be joined together in order to form one large fillet are sprinkled with TG on those areas where binding should take place afterwards. It is important that no fat or connective tissue is present on those areas of meat where binding should take place. Two or more pieces of meat can be sprinkled with TG and then placed together in a way that the sprinkled surfaces of meat are placed against each other in a casing or in a mould and there should be no air pockets between the individual pieces of meat after being filled. Those joint pieces of meat can be filled into a tight netting as well. The filled or moulded product is placed in the chiller for around 4–6 h and then, if required, into the freezer for a short while.

Once well chilled, or slightly frozen, slices of the same thickness can be cut from the reformed meat material.

*Method 2: wet addition*

TG is mixed with water and small pieces of meat are mixed with this slurry. The mix is subsequently filled tightly into a casing or mould and is placed at around 0 °C for at least 4–6 h, if possible overnight, for binding. Next day, portions of the same size and thickness can be cut. The addition rate of TG per kilogram of product by adding the material in a dry form or as a slurry depends on the blend offered by the supplier. Most of these blends containing TG consist of 90–98% non-TG materials such as sugars.

## **6.20 Blood-derived products for re-formed meat**

Larger pieces of meat can also be joined together by applying a two-step system using an animal protein as well as an enzyme. The animal protein is obtained by the separation of blood and the main component of this material is fibrinogen. Thrombin, an enzyme obtained by the separation of blood, is also used in this process. Thrombin must come into contact with the fibrinogen material to form bonds between individual pieces of meat. In order to bind pieces of meat together successfully, the fibres of each piece of meat should show the same direction once placed into a mould or into casings. Both substances are to be stored frozen and thawed prior to use in a water bath at 20–30 °C. Commonly, fibrinogen is sold in bags whilst thrombin is sold in small bottles. Fibrinogen is placed into a water bath for around 60–80 min whilst thrombin is placed in a water bath for around 40–45 min. The important point is that, once thawed, both substances should exhibit a temperature between 15 and 20 °C and not show any strands of protein within the clear solution. The fibrinogen:thrombin ratio is generally 20:1 and the thawed materials are mixed together in this ratio. From that point onwards, this solution has to be mixed with pieces of meat within 5–10 min and the mixed pieces of meat have to be placed immediately into moulds or prestuck fibrous casings. The filled moulds or casings are then left resting in the chiller at temperatures between 0 and 3 °C for at least 8–10 h. After this period of time, the product is sliceable. Care has to be taken because, once fibrinogen and thrombin are thawed, the shelf lives of those materials are very short. They can be stored between 0 and 3 °C for a maximum of only 6–8 h.

## **6.21 Allergens in meat products**

The number of people with food allergies is increasing and therefore most countries nowadays legislate to ensure that foods containing allergens are

clearly labelled. When an allergic reaction occurs, the immune system of the human body reacts towards normally harmless substances in a very strong way, producing antibodies such as immunoglobulin E (IgE). The severity of most allergies depends on the amount of food containing the allergen consumed as well as the sensitivity of the individual towards the allergen itself. An allergic reaction sometimes occurs only after numerous exposures to an allergen or even after several years of exposure. Pseudo-allergic food reactions are similar to allergic food reactions but are not caused by the production of a higher level of IgE by the immune system, as in real allergic food reactions. Pseudo-allergic reactions normally occur on first contact with the allergen, and dosage and impact are in direct relation.

Allergic reactions to food are normally caused by dietary proteins, e.g. histamine. In most countries, between seven and nine foods or food ingredients are classified as allergenic, the substances most commonly classified in this way being as follows.

- 1 Milk and milk products (lactose).
- 2 Fish and shellfish (prawns, lobster and crab).
- 3 Peanuts (ground nuts).
- 4 Eggs.
- 5 Sulphite.
- 6 Tree nuts such as almonds, cashews, hazelnuts, walnuts, pine nuts and pistachio.
- 7 Soy.
- 8 Gluten.
- 9 Sesame seeds.

These substances are responsible for around 90% of allergic reactions caused by consumption of a meat product. Extremely sensitive people also may show allergic reactions towards poppy, cotton and sunflower seeds, which can also be found in meat products. In addition to allergic reactions, people sensitive to gluten suffer from coeliac disease, a hereditary disorder of the immune system, in which the consumption of gluten causes damage to the lining (mucosa) of the small intestine. As a result, the absorption of vitamins and minerals is reduced. Around one in 3000 people suffers from coeliac disease.

A large number of countries today request mandatory labelling of food containing the substances listed above and the label of a meat product, therefore, usually clearly states which types of allergen are present. Statements indicating the possibility that an allergen may be present are only tolerated in certain countries, as they cause a great deal of uncertainty as well as confusion and are not helpful for the consumer. A statement such as 'may contain gluten' is usually introduced by the manufacturer to cover cases of cross-contamination or any other kind of unintentional contamination. Most supermarket chains, however, do not accept labelling indicating the possibility that an allergen may be present, arguing that, if hazard analysis critical

control point (HACCP) and good manufacturing practice are followed, then no accidental or unintentional contamination should take place. Manufacturers, nevertheless, disagree, arguing that some form of cross-contamination, even unintentional, is unavoidable, occurring through processes such as airflow.

## 7

# Colour in fresh meat and in cured meat products

As consumers assess product quality partly by appearance, an attractive and stable colour in meat and meat products has a major influence on the buying decision of the consumer. Much research has been carried out into ways of stabilizing the colour of fresh meat and optimizing the use of nitrite in cured meat products.

### 7.1 Retention of colour in fresh meat and uncured meat products

The colour pigment of the muscle tissue is myoglobin whilst haemoglobin is the colour pigment of the blood. The level of haemoglobin in meat depends largely on the degree of bleeding during the slaughtering process. Generally, the colour in raw meat is formed from around 90–95% myoglobin and around 2–5% haemoglobin, as lean meat is never totally free of blood. Haemoglobin exhibits a quaternary structure with four polypeptide chains (globin) each containing a haem group. The molecular weight of haemoglobin is 65 000 Da and the molecular weight of myoglobin is 17 000 Da. Myoglobin is therefore around four times smaller than haemoglobin. Some other proteins contribute to the colour of meat as well but on a very tiny scale and need not be discussed.

Myoglobin is a monomeric globular protein and is made from a protein, the colourless globin, with a colour-giving haem group. The haem group consists of a flat porphyrin ring exhibiting a central iron atom ( $\text{Fe}^{2+}$ ). This iron atom has six coordination links, called ligands, and four of those six

ligands are attached to nitrogen atoms whilst one is attached to the globin. Substances such as oxygen ( $O_2$ ), water or nitric oxide (NO) may bind to this sixth ligand and the state of oxidation of the sixth ligand plays a vital role in the colour of fresh meat.

Myoglobin is present in fresh meat in three different forms, which are in equilibrium with each other. Those three forms are reduced myoglobin, oxymyoglobin and metmyoglobin, and the 'final' colour of fresh meat is always a mix of these three forms of myoglobin. As long as the central iron core is present in its reduced state as  $Fe^{2+}$ , reduced myoglobin or oxymyoglobin is present. Reduced myoglobin is purple-red in colour because water is bound to the sixth ligand. The centre of pieces of meat usually exhibits such reduced myoglobin. Oxymyoglobin is bright red because oxygen is bound to the sixth ligand. Low temperatures support the formation of oxymyoglobin because at low temperatures, firstly, solubility of  $O_2$  is enhanced and, secondly, little oxidizing activity from enzymes can be seen. Metmyoglobin is obtained if the central iron atom is oxidized to  $Fe^{3+}$  by a loss of an electron (oxidation) and water is present on the sixth ligand. Metmyoglobin is brownish grey in colour and is mostly present in areas of low  $O_2$  concentration between the oxygenated outer layers of meat and anaerobic inner areas of meat. Such colour in meat is commonly seen in meat displays and is not attractive to the human eye because it is associated with the fact that the meat is no longer fresh.

Metmyoglobin cannot absorb  $O_2$  directly and therefore enzymes present in meat have to reduce metmyoglobin first to reduced myoglobin for  $O_2$  to be absorbed. Subsequently, reduced myoglobin can again take up  $O_2$  to form the red oxymyoglobin. If meat is stored for a prolonged period of time, this enzyme activity comes to an end and the metmyoglobin obtained cannot be reduced any longer to reduced myoglobin. As a result, no more oxymyoglobin can be formed and the colour of meat remains brownish grey. Even though a very thin layer of red oxymyoglobin is present on the surface of raw meat stored for a prolonged period of time owing to the impact on  $O_2$  on those surface layers, the majority underneath is metmyoglobin and the brownish-grey colour of metmyoglobin sooner or later dominates the meat colour overall.

The overall colour of raw meat is greatly determined by the amount of metmyoglobin present. Meat demonstrating up to 30% metmyoglobin still has an intense red colour and, even at a concentration of 30–45% metmyoglobin, the colour of meat is still red. Having 45–60% metmyoglobin causes a brownish-red colour and at 60–75% metmyoglobin the colour of meat is reddish brown. At concentrations of above 75% metmyoglobin the colour is brownish grey. Thus, the state of the globin plays an integral part in the colour of raw meat. As long as the globin is present in its native form and the iron ion is present in its reduced  $Fe^{2+}$  state, regardless of whether water or  $O_2$  is bound to the sixth ligand, the colour of meat is purple or bright red. Table 7.1 shows the different states of myoglobin.

**Table 7.1** Different states of myoglobin

	Oxidation	Sixth ligand	Colour	Globin
Myoglobin (reduced)	Fe <sup>2+</sup>	Water	Purple-red	Native
Oxymyoglobin	Fe <sup>2+</sup>	Oxygen	Bright red	Native
Metmyoglobin	Fe <sup>3+</sup>	Water	Brown	Native
Denatured globin	Fe <sup>3+</sup>	Water	Grey	Denatured

The colour of fresh meat also depends on the light-scattering ability of meat itself. PSE meat exhibits a small myofibrillar volume and demonstrates high light-scattering ability. As a result, such meat appears pale in colour. On the other hand, DFD meat shows a large myofibrillar volume and low light-scattering ability which allows light to penetrate deep into the muscle. Therefore, DFD meat is of dark-red colour. The concentration of myoglobin in grams per kilogram of lean meat follows the order beef → lamb → pork → poultry, with poultry exhibiting the least amount of myoglobin. Different cuts of the same animal demonstrate different levels of myoglobin as well. Table 7.2 shows such different concentrations of myoglobin in grams per kilogram of lean meat.

Generally, muscle tissue from male animals contains higher levels of myoglobin than meat from female animals. Also, muscles heavily utilized for movement such as shoulder and leg require more O<sub>2</sub>, which is transported primarily by red blood cells, resulting in a darker colour of muscle tissue than muscles such as breast (in poultry). Hence, the myoglobin concentration of heavily utilized muscles is generally higher than in muscles less used for movement. Animals kept indoors in confined conditions, where they are not able to move around, generally exhibit a lighter meat colour than free-range animals, which move around all day.

This also explains, for example, why chicken thigh meat is darker in colour than chicken breast meat or why pork shoulder meat is darker in colour than pork loin. The terms 'dark' and 'light' meat are commonly used to describe these differences in colour. Also, increased age of an animal causes an increase in the concentration of myoglobin, thus making meat darker.

Packed non-oxygenated fresh meat must be covered by a highly permeable packaging film in order to secure sufficient supply of O<sub>2</sub> for reduced myoglobin to form oxymyoglobin again and the O<sub>2</sub> permeability of packaging films should be around 6–7 l/m<sup>2</sup> day. Materials such as low-density polythenes are utilized for this type of packing film. Vacuum-packed meat is an unattractive purple colour as the presence of a vacuum (absence of O<sub>2</sub>) results in reduced myoglobin. The red and desired oxymyoglobin is restored quickly once the packaging is opened and meat is exposed to O<sub>2</sub> again. Oxygenated modified-atmosphere-packed fresh meat, however, should be covered with material exhibiting low permeability to maintain a high level of O<sub>2</sub> within the packaging. Hence, a gas such as carbon dioxide (CO<sub>2</sub>) is introduced in combination with O<sub>2</sub> in order to suppress bacterial growth.

**Table 7.2** Different concentrations of myoglobin

	Myoglobin concentration (g per kg of lean meat)
Beef	3.0–9.0
Lamb	4.0–6.0
Veal	1.0–2.5
Pork	2.2–6.0
Poultry, dark meat	1.0–3.0
Poultry, light meat (breast)	0.1–0.4

Generally, modified-atmosphere-packed fresh meat contains around 70–80% O<sub>2</sub> and around 20–30% CO<sub>2</sub>. Those high concentrations of O<sub>2</sub>, as well as being needed to maintain oxymyoglobin, favour the growth of aerobic bacteria such as *Bronchothrix* and *Pseudomonas*, which shorten the shelf life as both are aerobic bacteria and O<sub>2</sub> present is utilized as food. The introduction of CO<sub>2</sub>, on the other hand, keeps bacterial growth under control. CO<sub>2</sub> forms carbonic acid in conjunction with water coming from meat itself, which disrupts cell membranes.

Carbon monoxide (CO) must be kept away from fresh meat if a non-pink colour is desired because CO binds to myoglobin to form carboxymyoglobin, which is red in colour. CO is also highly toxic to humans as CO binds very solidly to haemoglobin and therefore blocks the transportation of oxygen within the bloodstream. The affinity of CO for haemoglobin is around 300 times greater than the affinity of oxygen for haemoglobin. This explains the toxicity of CO; it inhibits oxygen from binding to haemoglobin. CO exhibits a high affinity for myoglobin as well as for haemoglobin and creates a strong cherry-red colour in meat, which can last for up to 3 weeks and is therefore occasionally used in modified-atmosphere-packed fresh meat as it creates a strong and lasting red colour. However, because of its toxicity, CO is in most countries not permitted. In countries where CO is permitted, gas mixtures of 60–70% of CO<sub>2</sub>, 20–30% of nitrogen (N<sub>2</sub>) and 0.3–0.4% of CO are applied for fresh meat. The addition of small amounts of CO enhances the colour as well as having a positive impact on shelf life. High concentrations of CO, however, would cause a green colour in meat. Another risk in the use of CO is that meat spoiled microbiologically may still have a nice colour and therefore the consumer might be misled into thinking that the product was fresh. In a typical gas mixture containing CO, the high levels of CO<sub>2</sub> provide good shelf life and N<sub>2</sub> is used as a filler gas to replace O<sub>2</sub>. By using a CO gas mixture, an attractive colour is produced by the impact of CO and the shelf life is good because of the presence of CO<sub>2</sub>.

One way of bypassing the problem that CO is not permitted in many countries is by utilizing so-called 'tasteless smoke'. Legal authorities in most countries, nevertheless, see this as a way of adding CO to meat in an indirect, and illegal, way. Smoke generated at high temperatures is subsequently

filtered to remove the particular phase of smoke as well as all smoke-flavour-giving components, resulting in a material containing, besides some nitrogen complexes and O<sub>2</sub>, CO<sub>2</sub> as well as CO. The introduction of CO-containing tasteless smoke to packed fresh meat creates a lasting red colour without adding CO directly as an additive. Even though the amount of CO introduced this way is of no harm to human health, the consumer might be misled by the term 'tasteless smoke', which actually stabilizes the red colour and has no connection to smoking of meat. The effect of such tasteless smoke on the colour of fresh meat is comparable with around 0.4% CO present in modified-atmosphere-packed meat.

In summary, in modified-atmosphere-packed foods the gases normally applied such as CO<sub>2</sub> and N<sub>2</sub> fulfil the task of replacing O<sub>2</sub>; they therefore remove the O<sub>2</sub> required for growth of aerobic spoilage bacteria and delay rancidity. CO<sub>2</sub> is the active component against microbiological spoilage and N<sub>2</sub> fills the gap in order to exclude O<sub>2</sub>.

Meat from electrically stimulated carcasses of beef generally demonstrates a stronger red colour than non-stimulated carcasses as stimulated carcasses are cooled more quickly, thus increasing the solubility of O<sub>2</sub> in meat. The red tone in meat is also largely determined by the ratio of oxymyoglobin to reduced myoglobin. If oxymyoglobin is present at levels above 55% in comparison with reduced myoglobin, a strong red-cherry-like colour is given. Higher levels of myoglobin cause a change in colour towards a purple-red. In a 'master depot', meat is exposed under chilling conditions and oxygenated by almost 100% O<sub>2</sub> for around 12–18 h at a pressure of around 10 bar. As a result, O<sub>2</sub> diffuses into all areas within meat and an extremely high level of oxymyoglobin is obtained. Such O<sub>2</sub>-saturated meat, even displayed in a sliced state, exhibits a strong red colour after 2–3 days. If cut portions are afterwards packed under a modified atmosphere, the colour is stable for up to 6 days.

In spoiled meat, the colour pigment may be decomposed and globin separates from the haem group. As a result, the porphyrin ring is destroyed and the iron core separates from the haem. Ultimately, such meat will be of green colour as a result of the presence of green-coloured choleglobin. Aerobic bacteria can cause discolouration as some produce hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), which is a strong oxidizing agent, thus destroying the colour pigment and a green or pale colour is the result. Hence, species belonging to *Pseudomonas* can cause green and bluish colours as metabolic by-products. Hence, some bacteria produce hydrogen sulphide (H<sub>2</sub>S), which leads to the formation of sulphmyoglobin, resulting in green-coloured meat as well. Sulphmyoglobin can also be obtained in vacuum-packed meat at high pH values, generally at or above 6.2. *Micrococcus* can cause discolouration, creating an atypical red colour. Peroxides present in fatty meat, originating from fat autoxidation, can also transform myoglobin into metmyoglobin by oxidizing the iron core from its Fe<sup>2+</sup> into the Fe<sup>3+</sup> configuration, resulting in greening of meat.

In uncured cooked meat products, it is vital to reach certain core temperatures in order to stabilize the grey-brown colour completely. In this state, the iron atom is  $\text{Fe}^{3+}$  and the globin is denatured. In chicken a core temperature of 70 °C should be reached whilst a temperature of 72 °C is required in pork and beef to denature metmyoglobin fully. However, even fully cooked and vacuum-packed uncured meat products cooked to an internal temperature above 75 °C can occasionally exhibit a touch of red colour after 1–2 weeks, as anaerobic circumstances support post-cooking changes on myoglobin under chilled conditions.

The presence of globin haemochrome seems to be responsible for this occurrence and, once the product is removed from the vacuum packaging and exposed to  $\text{O}_2$ , the touch of pink generally disappears.

## 7.2 Nitrite and nitrate

Cured meat products should demonstrate a strong and stable red curing colour as the customer initially selects a product by sight. In order to obtain a stable red curing colour in meat products, sodium nitrite ( $\text{NaNO}_2$ ) is generally the material of choice.  $\text{NaNO}_2$  dissociates into  $\text{Na}^+$  as well as  $\text{NO}_2^-$  and nitrite is the water-soluble, highly toxic salt of nitrous acid ( $\text{HNO}_2$ ). For nitrite, and here specifically sodium nitrite, the lethal dose for humans is by around 1.1 g. For that reason, a mixture of salt and nitrite is commonly sold to manufacturers of cured meat products. The level of nitrite within such salt–nitrite mixtures varies generally between 0.5% and 20%, depending on the country's regulation.

Nitrite is a strong oxidizing agent and can cause pinking in non-cured meat products at levels as low as 3–5 ppm of nitrite per kilogram of meat product. Occasionally, potassium nitrite is utilized in applications such as low-sodium products. Based on the difference in molecular weight, around 30% more potassium nitrite has to be applied if the same impact on colour development is to be achieved compared with sodium nitrite.

Nitrate ( $\text{NO}_3^-$ ) is the salt of nitric acid ( $\text{HNO}_3$ ) and is also readily soluble in water. In meat products, potassium nitrate ( $\text{KNO}_3$ ) is the most commonly applied source of nitrate but, having said that, in a large percentage of all cured meat products, nitrite is the material of choice. Potassium nitrate dissociates into  $\text{K}^+$  and  $\text{NO}_3^-$  ions and is still sometimes introduced in products such as fermented salami dried for a long time as well as cured air-dried products. Nitrate does not contribute directly to the formation of the red curing colour and nitrite is the active component regarding the formation of the desired red curing colour. If nitrate is applied, it has to be reduced to nitrite, which then forms the curing colour in conjunction with myoglobin, the colour of meat.

Nitrite is utilized in meat products for the following reasons.

- 1 It promotes the red curing colour.
- 2 It provides the curing flavour.
- 3 It has a bacteriostatic impact.
- 4 It also acts as an antioxidant.

In cured meat and meat products, a strong and stable red colour is required and nitrite is the material of choice. To date, no substitute has been found for nitrite when considering the generation of a stable and appealing curing colour. In order to obtain a strong and stable curing colour in cooked cured meat products, around 30–50 ppm of nitrite are required per kilogram of meat product. However, 3–5 ppm of nitrite per kilogram of meat product are sufficient to create a pinkish tinge, which is generally not wanted in products such as roast pork (roast pork in most countries is a non-cured meat product) or other 'white' products such as chicken loaf. Therefore, great care has to be taken with products that should not be cured to ensure that not even traces of nitrite are introduced into such products in one way or another.

The curing flavour originates from reactions between nitric oxide (NO) with numerous substances naturally present in meat such as aldehydes, alcohols and inosine and, of great importance, with several sulphuric components. Different carbonyl complexes are also a result of the presence of nitrite and contribute to the curing flavour. Around 30–50 ppm of nitrite are required for the development of the typical curing flavour.

The antioxidative effect of nitrite is based on the fact that nitrite oxidizes to nitrate as well as forming solid complexes between the iron core of myoglobin as well as haemoglobin and therefore reducing the number of free iron ions ( $\text{Fe}^{2+}$ ). Free  $\text{Fe}^{2+}$  ions and some other pro-oxidative materials are bound by nitrite delaying the development of rancidity. Around 20–60 ppm of nitrite are needed for nitrite to act as an indirect antioxidant. NO binding to myoglobin and haemoglobin during the formation of curing colour does not give  $\text{O}_2$  the chance to bind to myoglobin and haemoglobin any longer and oxidation of myoglobin and haemoglobin is reduced as well.

Nitrite also acts as a preservative against bacteria such as *Salmonella* spp. and *Staphylococcus aureus* and especially against *Clostridium botulinum*. A concentration of 80–140 ppm of nitrite per kilogram of meat product is an effective hurdle against the growth of those bacteria especially in canned and retorted products. However, nitrite has relatively little impact against *Micrococcus* spp., *Lactobacillus* spp. and *Enterococcus* spp.

The impact against potential food-poisoning bacteria is one of the major reasons why nitrite is still permitted as an additive, as a ban on nitrite would most probably increase the number of severe cases of food poisoning. Nitrite is not accumulated in the human body and most humans do not consume nitrite-containing food on a daily basis. The impact of nitrite as a hurdle against bacterial growth in cured and cooked meat products is generally overrated mainly because 80–140 ppm are hardly present in the cooked

product given that most food standards in place do not permit levels as high as 140 ppm in a cooked product. Other hurdles, such as a low initial bacteria count of meat itself, sufficient cooking or thermal treatment of the product and storage of the cooked product at low temperatures exhibit overall a much greater impact on the shelf life of a meat product than purely the presence of nitrite does. Certainly, the fact that nitrite is present in a cooked product is better than its absence, but it should not be seen as the only means to ensure microbial safety. Obtaining proper levels of nitrite in the cooked product is of greater importance towards the maintenance of a strong curing colour than being the sole hurdle against unwanted bacteria.

A hint of pink colour in non-cured meat products can be the result of nitrite and nitrate present in spices, herbs or water utilized during the manufacture of products. Such materials utilized for the manufacture of meat products can contain nitrite, but more often nitrate, and up to 70 ppm can be seen per litre of water. Nitrate is reduced in the uncooked meat product to nitrite and formation of the red curing colour starts to take place. Also, an unwanted touch of pink in non-cured meat products can be obtained from combustion of coal or natural gas. Some by-products of direct-fired gas ovens, especially nitrogen dioxide ( $\text{NO}_2$ ), penetrate into the outer layers of a non-cured product and cause pinking as  $\text{NO}_2$  is water soluble. Hence, nitrite cross-contamination between nitrite-containing and non-nitrite products within a factory must be avoided in order to eliminate the risk of obtaining a pink colour in an uncured meat product.

Excess levels of nitrite in a meat product lead to discolouration known as nitrite burn and meat exhibits a green colour as a result. Nitrite burn is commonly seen at levels of nitrite above 600 ppm of nitrite per kilogram of meat and the formation of nitrihaemin, a green–brown-coloured pigment, is responsible for this process. Hence, nitrite burn is also partly connected to the pH value in meat products, and low pH values reduce the level of nitrite causing nitrite burn. Also, high levels of nitrite result in high levels of nitrous acid during the conversion of  $\text{NO}_2$  to nitric oxide ( $\text{NO}$ ) (see Section 7.3), and this temporary acid denatures myoglobin, which supports the formation of a green–yellow colour caused by nitrite burn in first place.

The presence of nitrite in meat products can cause the formation of nitrosamines, which can cause cancer; however, nitrosamines are only obtained if the nitrite is present in a meat product at the same time as secondary amines. Secondary amines are very seldom found in meat products and the amount of nitrosamine formed in cured meat products is therefore relatively low. During the formation of nitrosamine, nitrite forms nitroso groups ( $-\text{N}=\text{O}$ ), which react with secondary amines under the impact of heat. In cured meat products such as cooked sausages and cooked hams, the level of secondary amines is almost zero and therefore nitrosamines cannot be obtained. Also, in order to obtain nitrosamine the pH value of food must be below 5.6 and, of all meat products, only fermented salamis exhibit such pH levels in the finished product. Finally, temperatures above 140 °C (grilling) are required

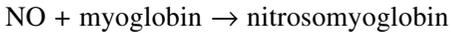
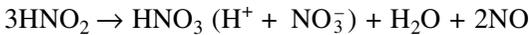
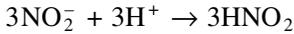
in order to form nitrosamines. Based on that, products such as pan-fried bacon is a potential but small risk only if heavily fried under high temperatures until virtually all fat is melted and a fat- and water-free material is obtained. A fat- and water-free material such as that would support the formation of nitrosamines if it were exposed to temperatures above 140 °C for a prolonged period of time. Raw fermented and acidified pizza salami (pH value around 4.6–4.8) is also a risk product, but only if heavily exposed to high temperatures and if a fat- and water-free product were obtained, which is highly unlikely, as in the case of bacon.

### 7.3 Mechanism of colour development in cured meat products

In most applications today, sodium nitrite is used and the application of nitrate happens very rarely because nitrite is the colour-giving component and also acts as a hurdle against bacteria growth. Potassium is rarely used in combination with nitrite as potassium nitrite but is frequently applied in combination with nitrate as potassium nitrate. When nitrate is added to a meat product, it has to be reduced first to nitrite to contribute to the formation of the curing colour and to act against bacteria growth. The reduction of nitrate to nitrite ( $\text{NO}_3 \rightarrow \text{NO}_2$ ) is a process accomplished by enzymes as well as bacteria and parameters such as temperature and pH value play a vital role within this reduction process. Nitrate is reduced to nitrite by the enzyme nitrate reductase and bacteria such as *Micrococcus* spp. produce this enzyme. Nitrate reductase only shows activity if the pH value is above 5.5 and the temperature above 8 °C. Such elevated temperatures speed up the process but cannot be fully applied within meat products as a microbiological risk would be the result. This explains why  $\text{NO}_3$  is generally not reduced any longer to  $\text{NO}_2$  in a cooked cured meat product, once stored at temperatures between 0 and 4 °C, and is therefore not available for stabilizing the curing colour in a cooked product. Hence, in a fully cooked meat product, the enzyme nitrate reductase is not present (active) any longer as it became denatured during thermal treatment and residual nitrate in a meat product is little use regarding the stabilization of the curing colour.

Once nitrite is obtained from nitrate, or when nitrite is added directly to a meat product (as is most commonly the case), the reduction of nitrite to NO ( $\text{NO}_2 \rightarrow \text{NO}$ ) depends on factors such as pH value, time, temperatures and the presence, or absence, of colour enhancers. Longer periods of time and elevated temperatures favour the formation of NO (as such factors generally speed up chemical reactions) but can be applied only in a limited way within meat products owing to microbiological risks. The presence of a colour enhancer speeds up the formation of NO as well. NO is an odd-electron-numbered very reactive gas and also a strong oxidizing agent. The reduction

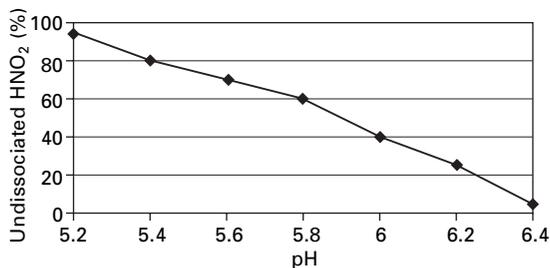
of nitrite to NO in a sour environment (as in a meat product) is a chemical process and no enzymes are involved. It is a spontaneous chemical reaction based on  $\text{HNO}_2$  obtained as an intermediate product.  $\text{HNO}_2$  is the conjugate temporary acid of nitrite and is unstable in solution. At a pH above 6.5,  $\text{HNO}_2$  is fully dissociated and is present as  $\text{H}^+ + \text{NO}_2^-$  ions. At such high pH levels, no NO can be obtained from dissociated molecules as only undissociated molecules of  $\text{HNO}_2$  can dissociate into NO,  $\text{HNO}_3$  and water. The reaction of  $\text{HNO}_2$  dissociating into NO follows the process



This reaction takes place at pH values below 6.5 and, in meat products, a pH value of around 4.7 (salami) to 6.0 is present in the final product; therefore the parameters for the formation of NO under slightly acid conditions are given. A pH value of 5.3 would be the optimum because all  $\text{HNO}_2$  is present in its undissociated form at this pH value and the optimum amount of NO would be obtained (Fig. 7.1).

Unfortunately, a pH value of 5.2 is the IEP of the actomyosin complex at the same time. This represents a conflict regarding WHC where high pH values around 6.0–6.4 are desired. As a consequence, formation of curing colour and WHC are contrary effects and the full potential cannot be obtained from either in a meat product. Having a pH value around 5.6–5.8 in the final meat product, such as cooked ham or cooked sausage, represents a compromise regarding WHC and formation of curing colour. In fact, in cured cooked hams, or cooked sausages, the pH value of 5.2, which would be the optimum for colour development, is never obtained and therefore the development of the curing colour in such products is never perfect.

The actual formation of curing colour takes place when nitrite, a strong oxidizing agent, oxidizes myoglobin quickly into metmyoglobin, which is brown–grey in colour. At the same time, NO is obtained from nitrite as described above via the intermediate step of  $\text{HNO}_2$  and binds to metmyoglobin



**Fig. 7.1** The level of undissociated  $\text{HNO}_2$  in relation to pH.

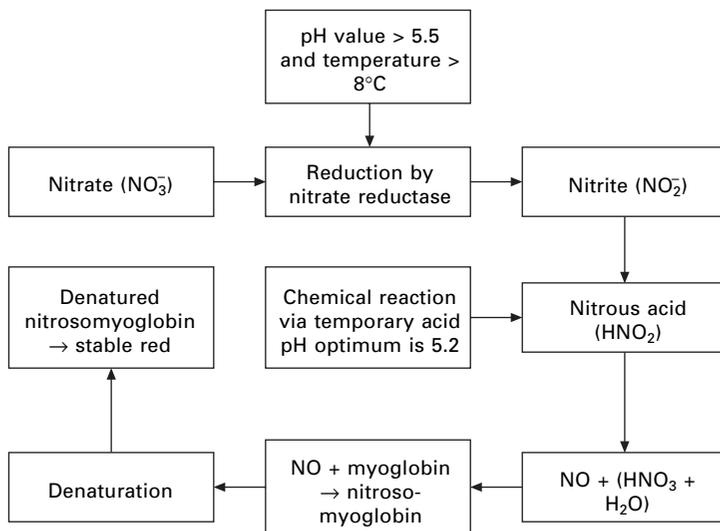
on the sixth ligand, resulting in nitrosometmyoglobin. Nitrosometmyoglobin is red in colour and has an  $\text{Fe}^{3+}$  ion. Nitrosometmyoglobin is subsequently reduced to nitrosomyoglobin, which is not fully stable yet. Only following denaturation, can nitrosomyoglobin decompose into globin and nitrosomyochromogen, the pink and finally stable curing colour in meat products (Fig. 7.2).

In other products, such as raw fermented salami, nitrosomyoglobin is denatured by the impact of acidification by pH values at 5.2 (IEP) and below. In slow fermented and non-acidified salami, as well as in cured and dried meat products, the combination of low  $A_w$  with a high concentration of salt denatures nitrosomyoglobin as well.

NO can be obtained in two ways: firstly, in slightly sour media such as a meat product, NO is obtained when  $\text{HNO}_2$  is formed from nitrite within a chemical process; secondly, it is obtained when ascorbic acid directly reduces residual nitrite via  $\text{HNO}_2$  to NO following the reaction  $2\text{HNO}_2 + \text{ascorbic acid (C}_6\text{H}_8\text{O}_6) \rightarrow 2\text{NO} + 2\text{H}_2\text{O} + \text{C}_6\text{H}_6\text{O}_6$  (dehydroascorbic acid).

The main reasons for poor colour development and colour stability in meat products are as follows.

- 1 There was insufficient myoglobin in meat, which, unfortunately, cannot be altered.
- 2 Insufficient nitrite was introduced into the meat product in the first place.
- 3 No, or insufficient, colour enhancer (ascorbic acid and ascorbate) was utilized.



**Fig. 7.2** The mechanism of curing colour development.

- 4 The time provided for colour development prior to heat treatment was too short.
- 5 Excess levels of O<sub>2</sub> were present in the product (application of vacuum is of advantage during several processing steps).

The final colour of a cured meat product always contains to some degree metmyoglobin as well as some oxymyoglobin but nitrosomyoglobin is by far the largest portion. It is never the case that all myoglobin is converted into nitrosomyoglobin and that no metmyoglobin or oxymyoglobin would be present at the same time. Green discolouration of cured meat products such as cooked ham is occasionally caused by the presence of strong oxidants such as H<sub>2</sub>O<sub>2</sub> produced by heterofermentative *Lactobacillus fluorescens*. Very strong oxidation leads ultimately to the formation of a verdohaem complex, which is green in colour. Further oxidation results in a yellowish colour. Sufficient heat treatment of cooked products generally eliminates heterofermentative *Lactobacillus* spp. and core temperatures of 70–72 °C are required. Greening and other forms of discolouration in cured cooked meat products are commonly signs of poor hygiene present in the factory. Hence, machines utilized during the production and slicing of the finished product must be kept clean and free of any cleaning and disinfection materials as those materials are either very alkaline or acid by nature.

Fading of curing colour is also greatly enhanced by the impact of light. Complexes containing NO are susceptible to photodissociation (photolysis) and the impact of light reduces colour stability as a result. In cooked cured products, a fair amount of added nitrite is oxidized to nitrate by oxidase enzymes and is not available for colour development any longer. Poultry products, as well as all other non-cured meat products, can exhibit an unwanted pink colour as a result of the unintentional contamination of such products with nitrite. Nitrosomyoglobin can be formed as a result of introducing nitrite-contaminated spices, water and other materials. CO obtained from direct-fired gas ovens can produce CO haemochrome, which causes discolouration by forming an undesirable pink colour on the surface on non-cured meat products.

## 7.4 Colour enhancers

The reaction from NO<sub>2</sub> via HNO<sub>2</sub> finally to NO, as well as the binding of the NO to myoglobin, takes place very slowly at the pH levels present in meat (around pH 5.5–6.2). Colour formation also takes place at quite low temperatures during various processing steps and low temperatures slow down chemical processes as well. The addition of substances such as GDL, ascorbic acid, ascorbate, isoascorbate or citric acid speeds up the process of colour formation and also stabilizes curing colour in the finished products. For a faster formation of curing colour, all those materials slightly reduce the

pH value in a meat product and higher levels of undissociated  $\text{HNO}_2$  are obtained. As a result, more NO is produced and the curing colour is enhanced as the result. The function of a colour enhancer could also be said to 'kick-start' the process because nitrite decomposes by itself into  $\text{HNO}_2$  at a pH value at or below only 5.7. Unfortunately, most meat products exhibit a pH value above that level, thus requiring a substance to start the conversion from nitrite into NO via the formation of temporary  $\text{HNO}_2$ .

The most commonly applied colour enhancers are ascorbic acid, ascorbate and erythorbate (isoascorbate).

Sodium ascorbate is the sodium salt of ascorbic acid whilst erythorbate is the salt of erythorbic acid. There is no difference from a technological point of view between erythorbate and ascorbate in a cured meat product regarding the stabilization of curing colour except that around 10% more erythorbate has to be introduced than ascorbate in order to show the same impact with regard to stabilizing the colour. The enhanced addition of erythorbate is based on the difference in molecular weight. Interestingly, ascorbate stabilizes the red curing colour in cured non-cooked meat products which are packed under vacuum but speeds up discolouration if the same cured non-cooked product is stored under the impact of  $\text{O}_2$  (non-vacuum packed) and light. Under the impact of  $\text{O}_2$ , the unstable nitrosomyoglobin turns into a buffer (antioxidant) for NO radicals and ascorbate supports this process. As a result, NO separates from myoglobin and the impact of light speeds up the separation of NO from myoglobin even more.

Ascorbic acid is a strong reducing agent, enabling the fast and direct formation of NO from residual nitrite, and enhanced levels of nitrosomyoglobin is the result, thus stabilizing the curing colour obtained initially. It is primarily utilized in cured cooked sausages at around 0.4–0.6 g (400–600 ppm) per kilogram of meat product. Ascorbic acid also reacts with the temporary  $\text{HNO}_2$  during the conversion of nitrite into NO, speeding up the formation of NO in this way. Ascorbic acid is vitamin C but in most countries this vitamin image cannot be promoted as a marketing or sales tool. Isoascorbic acid has exactly the same effect in stabilizing the developed curing colour but is not a vitamin. Ascorbic acid also acts indirectly as an antioxidant as it stabilizes hydroxyperoxides, which are obtained by the formation of metmyoglobin, as well as being an oxygen scavenger in its own right.

Greening in cooked sausage can be caused by bacteria but can also be due to excess addition of colour enhancers such as ascorbic acid. Excess levels of this colour enhancer cause the formation of large amounts of  $\text{HNO}_2$  within a short period of time, which ultimately causes myoglobin to turn green or, in severe cases, even yellow. Excess levels of acids can denature myoglobin prematurely and extremely pale or slightly yellow–green colours can be seen in the finished product.

Ascorbic acid must never be applied at the same time as nitrite to meat products such as cured cooked sausages, and must never be mixed into ham brines containing nitrite. When nitrite and ascorbic acid come into direct

contact, an instant chemical reaction takes place resulting in the formation of nitrogen oxides (NO). The main nitrogen oxides formed are NO and NO<sub>2</sub>. NO and NO<sub>2</sub> are the only two stable forms of nitrogen oxides at room temperature and NO turns into NO<sub>2</sub> in the presence of O<sub>2</sub> ( $2\text{NO} + \text{O}_2 \rightarrow 2\text{NO}_2$ ) as NO is a highly reactive substance. Both NO and NO<sub>2</sub> are toxic and NO<sub>2</sub> has a brown-red colour. NO and NO<sub>2</sub> must not be confused with other nitrogen oxides such as nitrous oxide (N<sub>2</sub>O), or laughing gas, which is used in combination with O<sub>2</sub> as an anaesthetic. The nitrite required within the meat products is used up if nitrite and ascorbic acid are added together, and discolouration will be seen in the final product owing to the lack of nitrite. Therefore, sausage premixes for cooked cured sausages cannot contain nitrite and ascorbic acid at the same time and compounds for ham brines cannot contain those two additives either. When producing a cured cooked sausage, nitrite and ascorbic acid have to be added separately into the sausage mass. A possible solution for the simultaneous presence of nitrite and ascorbic acid in a premix would be the use of encapsulated (fat-coated) ascorbic acid but such attempts did not prove to be successful in the commercial world.

In ham brines, ascorbate or erythorbate is utilized as ham brines exhibit pH values above 7 (generally around 7.6–8.4) and are therefore alkaline. In an alkaline solution, no ascorbic or erythorbic acid is formed from ascorbate or erythorbate and no reaction between nitrite and ascorbate will take place within the brine. The formation of ascorbic or erythorbic acid from ascorbate or erythorbate will only start once introduced into meat, as slightly acidic conditions are present in meat and a certain degree of undissociated ascorbic or erythorbic acid is obtained under such sour conditions.

Because of its lower molecular weight, slightly more ascorbate or erythorbate has to be applied for every kilogram of meat product to achieve the same effect as when only ascorbic acid is applied (ascorbic acid cannot be applied in all applications because of its instant reaction with nitrite). To be more specific, 87 g of ascorbic acid is as effective as 100 g of ascorbate. Ascorbate is generally applied at 0.4–0.6 g per kilogram of meat product whilst erythorbate is generally introduced at 0.5–0.8 g per kilogram of product. Ascorbate is the salt of ascorbic acid but costs significantly more than erythorbate. The vitamin character of ascorbic acid (vitamin C) cannot be promoted within meat products as vitamin-enriched meat products are not permitted.

Ascorbic acid, or ascorbate, has three major functions in cured cooked products. Firstly, it reduces nitrite directly to NO and facilitates the formation of nitrosomyoglobin. It accelerates the formation of the red curing colour which would take place without it as well but at a much slower speed. Secondly, it stabilizes the curing colour by acting as an antioxidant, neutralizing, or deactivating, peroxide radicals on the surface of the product once that surface is exposed to O<sub>2</sub> and UV light. Thirdly, by reducing the level of nitrite in the cooked finished product it prevents, or reduces, the formation of nitrosating agents such as N<sub>2</sub>O<sub>3</sub> and thus the formation of nitrosamines.

A solution of ascorbic acid and water is frequently sprayed into canned

products in the space between the product and the lid. The external addition of ascorbic acid reduces, or eliminates, greening on the surface of the product where the surface does not touch the lid during retorting.

GDL is occasionally introduced as a colour enhancer at 1–2 g per kilogram of sausage mass but must be added at the end of the cutting process once a stable emulsion has already been obtained. In some cases, a combination of GDL and citric acid is utilized as well and around 1 g of such a blend is applied to every kilogram of sausage mass. Both substances lower the pH value in the sausage mass and therefore elevated levels of undissociated  $\text{HNO}_2$  are obtained. As a result, more NO is formed which contributes to a stronger curing colour. Such sour additives are utilized to lower the pH value by around 0.2 pH units in a well-binding sausage mass containing high levels of activated protein. Within low-meat emulsified sausages, this addition of sour additives is not recommended and ascorbic acid or ascorbate is the material of choice. Within a low-meat sausage, the amount of activated protein is quite low overall and the addition of sour additives drives the pH value drastically towards the IEP, which reduces WHC once more. Those sour additives also should not be utilized in ham brines at all because those substances are acids, which react with nitrite in the presence of water. Citric or lactic acid is infrequently applied as a colour enhancer at around 0.7–1.0 g per kilogram of sausage mass. However, if GDL, citric acid or lactic acid is introduced as a colour enhancer in cured sausages, the amount of those substances added must not lower the pH value of the uncooked meat product overall below 5.8–5.9. If the pH value were to drop below 5.8, a significant negative impact regarding WBC, firmness of the product and reduced cooking yields would be seen.

## 7.5 Measuring colour: the $L^*-a^*-b^*$ system

The human eye is a very specialized instrument and can distinguish about  $7 \times 10^6$  different colours. Of those  $7 \times 10^6$  colours, only around 3000 have a

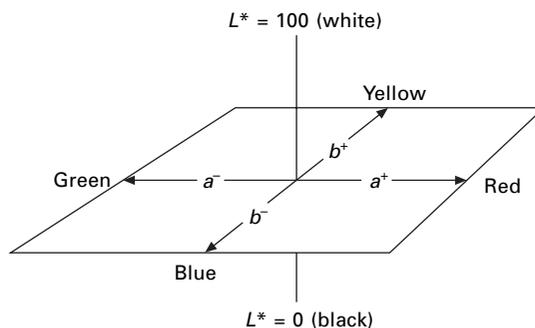


Fig. 7.3 The three-dimensional structure of the  $L^*-a^*-b^*$  system.

specific name and only 12 out of those 3000 are utilized in everyday life. The colour of meat or of a meat product can be measured and represented using the  $L^*-a^*-b^*$  system (Fig. 7.3).

The  $L^*$  value represents the difference between white and black; an  $L^*$  value of zero is black whilst an  $L^*$  value of 100 is white. A positive  $a^*$  value, or  $a^+$  value ranging from 0 to +50, represents the red tone of the product. Higher  $a^+$  values indicate a darker-red colour. A negative  $a^*$  value, or  $a^-$  value ranging from 0 to -50, represents the green tone of a sample and -50 is the darkest green tone. A positive  $b^*$  value, or  $b^+$  value ranging from 0 to +50, represents the yellow tone of a sample. A  $b^+$  value of +50 is the strongest yellow tone. A negative  $b^*$  value, or  $b^-$  value ranging from 0 to -50, represents the blue tone of a sample and, here as well, -50 is the strongest blue tone.



## **Part II**

### **Technologies for particular meat products**



## 8

# Whole-muscle brine-injected products

Cooked hams occur in a huge variety of forms, shapes and tastes around the world. Although in some places in the world (e.g. Europe) the term 'ham' refers only to pork, elsewhere cooked hams are produced using pork, beef, turkey, chicken and even exotic meats such as crocodile, fish and kangaroo. Flavours such as garlic, juniper, red wine and celery are added to create an even wider range of products. The term ham specifically refers to meat from the leg, but many cooked ham products are made from other cuts of meat following a process of injecting, tumbling and heat treatment.

In Europe and most other parts of the world, whole-muscle products are primarily made from pork. Places such as Austria and Germany still produce very-high-quality products, following a protein:water ratio of 1:4. So that this protein-to-water ratio can be achieved in the finished product without adding proteins to the ham in order to enhance the level of protein artificially, a cooking yield of around 115% is the maximum. Higher cooking yields would result in a water content that is more than four times the protein content.

The traditional method of producing hams by soaking pieces of meat in brine before heat treatment is very rarely practised today. High cooking yields are the norm in most parts of the world, and the price that consumers are willing to pay for a whole-muscle product generally determines the cooking yield and eating qualities of such products. Cooked hams frequently exhibit a very high  $A_w$  and are therefore prone to microbiological spoilage, which can negatively affect flavour and colour.

Boneless cooked ham products are commonly consumed in a cold state after heat treatment. Bone-in products may be consumed hot as well, after reheating. Cooked ham products are extremely popular, as they can be eaten

on their own and in conjunction with other foods, and cooked hams are also often used for fillings. Another advantage of ham products is that most are very low in fat, which means they match current consumer demand for healthy low-fat food. The following chapter covers the production of re-formed whole-muscle products and injected meat products made from individual muscles. The processing steps for producing cooked ham and other meat products should take place in sequence, each one following smoothly from the previous step. It is best if materials flow through the factory in one direction because this optimizes the use of machinery and staff. When material moves back and forth, not only is it very expensive in time, but also there is a high risk of cross-contamination, which is critical in each step of the process.

## 8.1 Selection and preparation of raw materials

Manufacturers who process frozen meat have to rely on the specifications given by the supplier of the raw meat, as direct selection of the raw material to be processed is generally not possible. Companies that buy large volumes of frozen meat frequently visit their suppliers and specify the standard of meat that they require; thus they can tailor the raw materials to the meat product being manufactured. Typically the cut of meat, fat content and microbiological data are specified, and additional information such as particular methods of trimming can also be stated. Quite a large number of processors buy meat in this way because it removes the need for an in-house boning department. Where fresh chilled meat is used, all pieces of meat should be deboned in a way that avoids as much as possible making deep cuts into the muscle tissue.

The meat to be processed should be at a temperature of 0–3 °C and the bacteria count, whether fresh chilled or frozen thawed, should be as low as possible, preferably between  $10^2$  and  $10^4$  per gram of meat. A low initial bacteria count has two benefits, firstly, because it helps to keep the bacteria count low throughout the manufacturing process and, secondly, because it greatly enhances the shelf life of the cooked product. The initial bacteria count is affected by many factors, from the level of hygiene applied in abattoirs during slaughtering, transport of carcasses and how the meat is deboned, to how frozen meat is defrosted prior to processing.

Meat to be processed must be fully thawed prior to injection and no frozen or even semifrozen areas must be left in the meat, because injecting brine into frozen meat is not technically possible. This is particularly important for large pieces of meat, such as entire pork legs with the bone in. If semifrozen meat is injected, there will be areas where injection is incomplete and hence areas where the levels of functional additives will be low, which will affect curing colour, flavour and protein activation in those areas. Injecting brine into semifrozen meat destroys the fibre structure of muscle tissue and results in visible gel pockets in the finished product.

Thawing frozen meat with running water is the quickest way of defrosting but unfortunately also the worst method to use. Valuable water-soluble proteins are washed out and, as cellular ice turns back quickly into water, the damaged muscle cells have little time to reabsorb cellular water, resulting in a high thawing loss. A thawing loss of between 8% and 14% is quite common using this method, which is very significant economically. The level of thawing loss correlates with the temperature of the water used for the thawing process, and higher water temperatures increase the level of thawing loss. An enormous amount of water is required to thaw meat under running water and most companies have to pay twice for the water that they consume, firstly, for the water as it comes into the factory from the public water-supply system and, secondly, for the volume of water that enters the drainage or sewage system.

When meat is thawed with running water, the temperature of the meat is ultimately the same as the temperature of the water. The temperature of running water is typically around 10–15 °C. In some places, this temperature can be even higher and large variations in water temperature can be seen between summer or winter.

A perfect breeding ground for bacteria is created when meat is thawed with warm water, thus making it more difficult to keep the initial bacteria count low. A high bacteria count in the raw material must be counteracted with a more severe heat treatment or cooking process, which in turn either enhances cooking losses or increases the risk of water separation when the product is filled into a waterproof casing. Neither of those scenarios is desirable. An increased number of bacteria also makes the shelf life of the product shorter and affects colour stability and flavour.

Thawing in cold air at around 4–8 °C reduces the amount of thawing loss but requires significantly more time and a greater amount of thawing space. Thawing in cold air results in a thawing loss of around 4–8% on average, with higher thawing losses at higher temperatures. The temperature should not be above 7–8 °C, as bacteria such as *Salmonella* spp. grow well at such temperatures and, because of the time required for thawing, there is a serious microbiological risk. Frozen meat can also be thawed in tumblers, into which steam is injected at intervals. The major advantage of this method is that there is no thawing loss; indeed sometimes there is a gain of around 1–2% in weight. The downside is that several tumblers are needed if large volumes of meat are to be defrosted, as a thawing cycle takes around 10–14 h. However, avoiding loss during thawing justifies the cost of installing such machines fairly quickly.

Thawing can also be carried out using high-speed air. The frozen blocks of meat are unpacked, leaving a plastic liner to cover them, and placed on racks in a large room. Temperature probes are placed in the core of the meat and at several other places just underneath the surface. Steam is injected into the room for a short period of time and then quickly cooled because of the rapid airflow through the room. This cycle of injecting steam and subsequent cooling is repeated countless times over 12–18 h, and the meat is completely

thawed at a temperature of between 0 and 3 °C, which is ideal for further processing. Different steam-thawing programmes are used depending on the material to be thawed, and a thawing loss of around 4–5% is observed, significantly less than thawing in running water.

Using microwaves to thaw meat has been tested intensively, but so far this method is not useful for meat processors. Large pieces of meat tend to remain frozen in the middle while the surface layers start to show signs of being partially cooked. Microwaves raise the temperature from –20 to –4 °C in a very short period of time and minimal loss in weight, if any, is seen. The problem is in raising the temperature from –4 to 0 °C. Within this temperature zone, a change in phase occurs and ice turns into water, which requires much energy. During this change in phase, droplets of water are present on the surface of the meat, and the continuous impact of microwaves creates a magnifying-glass effect; so these water droplets ‘cook’ the meat on the surface.

Thawing loss is a loss in meat weight, and not just a loss of water, because the meat already contains water before processing. It has been demonstrated that thawing in high-speed air can result in a saving of up to 100% and more compared with thawing in running water. For instance, if a company defrosts 10 tons of meat every night, using the high-speed air method, there is a thawing loss of 5%, or 500 kg. Using the running-water method to defrost 10 tons of meat results in a loss of 10%, or 1000 kg. Therefore, using the high-speed air method results in a net saving of 500 kg of meat per 10 tons. If those 500 kg of meat saved are used to make injected products, then they will produce around 600 kg (or more, depending on injection rate and additives applied) of finished ham products. If the same scenario takes place five times a week, around 3000 kg of additional ham products are the net result per week; hence a substantial saving is achieved in a very short period of time and the cost for installing a high-velocity air thawing room is repaid quickly. In addition to these financial savings, meat thawed by the high-speed air method is at the ideal temperature for further treatment, avoiding the problems associated with meat that is warmed during the thawing process.

The individual muscles to be processed for re-formed whole-muscle ham products should be free of any surface fat, as surface fat will interfere badly with the binding between the individual muscles and result in poor slice coherency. Visible pieces of fat within a whole-muscle ham are not appealing to the consumer, either, as the image of whole-muscle products is lean and light. Sinews, ligaments, tendons, glands, blood spots and bloody tissue should all be removed as they would also be visible in the finished product and affect coherency, or binding between individual muscles. Slice coherency is at its best when there is activated surface protein on both pieces of meat, and it is improved greatly by membrane skinning of the individual muscles. Special machines are available for membrane skinning and the process is quick. This process removes the thin layer of connective tissue surrounding the muscle (perimysium) and makes it easier to introduce brine into the muscle. By removing the layer of connective tissue from the surface of a

muscle, which acts a barrier, lean muscle surface is exposed to a significantly great degree and surface protein can be activated much more effectively. An increased amount of activated surface protein on each muscle results in excellent slice coherency. Membrane skinning also increases cooking yield of the product. The pieces of meat are also more elastic and softer after tumbling and therefore easier to handle during subsequent filling into the respective casing, mould or netting than if the layer of connective tissue were still present. The amount of material removed from the individual muscles during membrane skinning (mainly connective tissue) is small, and this material can be used for cooked sausages such as hot dogs. It is an excellent raw material for increasing firmness and bite in emulsified cooked sausages as it is rich in connective tissue, which contains a high degree of collagen. Collagen turns into gelatine during heat treatment of the sausage and increases firmness and bite.

Given that injected hams are generally produced from whole muscles, the use of PSE pork should be avoided, as it can result in a pale finished product or lower cooking yields. Severe PSE meat, owing to the denaturation of proteins after slaughtering (see Chapter 4, Section 4.1), can exhibit a mushy soft texture in the finished product, giving it an almost non-cooked appearance. The use of PSE meat overall has no advantages but causes higher cooking losses, and a drier and pale finished product. Proper selection of the raw material to be processed for PSE eliminates such shortfalls.

When processing pork for whole-muscle ham products, the meat to be injected is often 36–76 h 'old'. Such matured meat exhibits a higher pH, which is beneficial for WHC and the solubility of protein. Meat with a pH of around 5.7–6.1 exhibits greater repulsion forces between the protein molecules and hence more added water can be immobilized within the protein structure, resulting in enhanced cooking yields. Maturing of meat also enhances the solubility of protein in response to additives such as phosphates and salt, and the WBC is positively affected owing to an increased amount of solubilized protein. Processing meat with a pH of 5.5, rather than meat with a pH of 5.8, seems to represent a very small difference, only 0.3 pH units. However, considering that the pH of useable meat is in the range 5.3–6.3, a rise of only 0.3 pH units represents an increase of around 30%, which is significant.

Matured meat is even more beneficial in ham products produced with few additives, such as only phosphates and salt, as the increased solubility of protein is more important. Many ham products are produced by injecting meat which has matured for only around 18–24 h, resulting in a minimal rise in pH, but this is compensated for by the addition of additives such as phosphates.

Different individual muscles demonstrate different shades of red. As a result, quite opposing shades of red colour can be seen in the finished product if a dark-coloured muscle appears next to a light-coloured muscle. Top-quality hams are produced out of the same type of individual muscle, such as topside only, to achieve an even curing colour in the finished product. A

two-tone effect can be seen occasionally, where light- and dark-coloured areas are present within the same muscle. These light- and dark-coloured areas are primarily associated with different levels of myoglobin and different pH levels within the same muscle, but the phenomenon of two-toning is not fully understood. One explanation could be that different levels of enzyme and/or metabolic activity are taking place in different parts of the same muscle. The severity of this two-tone effect is seen to a lesser degree after meats have been cured and cooked.

The WME in pork (see Chapter 4, Section 4.3) is difficult to maintain, given that injection and subsequent distribution of the brine and all additives within the meat has to take place within 60–90 min after slaughter. The brine injected has to cause rapid swelling of the muscle fibres actin and myosin, and the gap obtained between actin and myosin has to be large enough to prevent myosin from binding to the actin during subsequent rigor mortis. Injection of meat while the bones are still in is the only option, and deboning of the injected meat occurs afterwards. The injection has to take place while the pH in the meat is at, or above, 6.3–6.4. During the subsequent deboning, the salt and water injected cause the required swelling. Maintaining and using the WME results in around 4% higher cooking yield and an improved slice coherency in the finished product. However, owing to the difficulty of the process involved and deboning of injected meat, use of WME in whole-muscle pork products is rare.

DFD beef results in a good cooking yield because the solubility of protein is high but has a negative impact on curing colour and shelf life of the finished product owing to insufficient acidification during rigor mortis (see Chapter 4, Section 4.1). The excellent solubility of DFD protein is based on the low numbers of cross-links between actin and myosin during rigor mortis.

Membrane skinning is not required for injected turkey products, commonly made from turkey breast, because the material is much softer in texture by nature compared with beef or pork, and protein is activated more effectively as a result. Hence, a boneless turkey breast has quite a large area of open meat surface and the connective tissue, covering other areas of the muscle, is much thinner than the connective tissue covering muscles of pork or beef.

## 8.2 Selection of additives

Additives used in whole-muscle products are primarily chosen based on the desired level of injection, which in most cases correlates with cooking yield in the finished product. Table 8.1 shows the most commonly used combinations of additives based on the level of injection.

Additives such as phosphates and salt are generally always used, other additives are selected according to the requirements of the manufacturer. Phosphates and salt are responsible for the activation of protein present within lean muscle tissue, which is the expensive component in lean meat.

**Table 8.1** Commonly used combinations of additives in injected ham

Level of injection (%)	Functional additives utilized
10–30	Phosphates, salt
30–50	Phosphates, salt, carrageenan (or protein such as soy instead of carrageenan)
50–70	Phosphates, salt, carrageenan protein
70–100	Phosphates, salt, carrageenan, protein, native and/or modified injectable starch

However, from time to time ham is produced without added phosphates to respond to trends in sales and marketing campaigns. Additives such as citrate, carbonates, carrageenan, starch and proteins are sometimes introduced in an attempt to obtain acceptable cooking yield, firmness, texture and bite but are not totally successful. The addition of citrate enhances the ionic strength and increases the swelling of the protein fibres but does not solubilize protein. Carbonates raise the pH in the meat and, by doing so, contribute to a higher WHC. However, a combination of citrate and carbonates is still far less effective at solubilizing protein than phosphates in combination with salt (phosphates and salt only dissolve protein when combined).

Activated meat protein is still the best material for achieving good slice coherency, bite and texture in the finished product. No-added-phosphate hams do not make sense from a technological viewpoint because protein is the most valuable part of lean meat and by not using phosphates, the expensive protein is not used effectively. Meat itself contains some phosphate, and so terms such as ‘no added phosphate’ are generally used, rather than ‘phosphate free’. Phosphates, or a blend of phosphates, used in ham brines must dissolve quickly and completely in cold water (see Chapter 5, Section 5.1) for optimal functionality. Blends of phosphates contain predominately long-chained polyphosphates because of their excellent solubility in cold water, and occasionally a few shorter-chained phosphates such as tetrasodium pyrophosphate, which acts quickly on muscular protein. Most countries permit the use of phosphates up to a level of 0.5%, or 5 g, of phosphorus pentoxide ( $P_2O_5$ ) per kilogram of product. A  $P_2O_5$  content of 0.5% corresponds to around 8–9 g of added phosphate per kilogram of finished product, but such high levels of added phosphates do not result in any advantage from a technological point of view. A phosphate level of 4–6 g per kilogram of product, and not as  $P_2O_5$ , is fully sufficient. Care has to be taken to ensure that the maximum pentoxide  $P$  value of a ham product is not exceeded in countries where this regulation is in place.

The  $P$  value is important for ham products where the manufacturer claims that no phosphate was added during production. The  $P$  value is obtained by the formula  $P = [P_2O_5 \text{ content (\%)} \text{ of product} / \text{protein (\%)} \text{ of the product}] \times 100$ . Hams produced without the addition of phosphates generally have a  $P$  value between 1.8 and 2.2. Added phosphate increases the  $P_2O_5$  content

within the formula while the level of protein in the finished product remains unchanged. Therefore, even small amounts of added phosphate result in a *P* number above 2.4, which is the point above which it is highly certain that phosphates were added during the production process.

The grey area within this scenario is due to the gap between the natural  $P_2O_5$  content of a ham (without added phosphate), around 1.8–2.2, and the level of legal importance, which is 2.4, as explained above. Given that the addition of even very small amounts of phosphate results in increased WBC, phosphates are sometimes added in an amount that will keep the final *P* value below 2.4. It would be illegal to sell a product such as this as a no-added-phosphate ham, even though the final *P* value does not exceed 2.4. The fact that phosphates were introduced during the manufacturing process, regardless of the fact that the *P* value remains below 2.4, prohibits the sale of such a product under the no-added-phosphate claim. The blend of phosphates used in brines prepared for injected ham typically has a pH of around 9.0. Blends that have a pH of 10.0 or higher have a negative impact on the formation and stability of the curing colour, because less undissociated nitrous acid is formed during the conversion from nitrite to NO. As a result, less nitrosomyoglobin is obtained (see Chapter 7, Section 7.3). Using high-pH phosphates also favours unwanted bacterial growth, and can produce an alkaline, or soapy, taste in the finished product.

Injectable soy isolates and occasionally injectable soy concentrates are commonly introduced in highly extended ham products. The usage rates of soy protein vary greatly and range between 5 and 40 g per kilogram of finished product. Injectable soy isolates immobilize around five parts of water and the ability to emulsify fat, mainly seen in soy isolates, does not play a significant role in the production of whole-muscle ham. The addition of soy isolates produces a gel, which gives texture and bite to the finished product. Injectable soy concentrates, and there are not many on the market, bind around four parts of water but are significantly cheaper than soy isolates. Soy concentrates do not form a gel and therefore their contribution to the firmness of the finished product is less than that of a soy isolate. However, the presence of other additives such as carrageenan and starch can cause a soy concentrate to be as effective as an isolate. The low temperature of the water used for the preparation of brine slows down the hydration of soy but avoids lumping of the material. During preparation of the brine, soy has to be mixed with some degree of shear for around 5–10 min to disperse and hydrate the material fully. Some types of low-cost soy proteins can block filters and needles and also have a strong yellow–grey colour, which negatively affects the curing colour of the finished product.

Blood plasma is another highly functional protein which increases the swelling of protein, because it has a pH above 7.0. It also binds water well on its own. Wheat protein isolate is also used and is very neutral in taste and colour. This material also demonstrates excellent dispersibility in brine and does not block the needles, so that even high inclusion levels do not increase

the viscosity of the brine significantly. Being neutral in taste, high inclusion levels do not interfere with the natural taste and flavour of the meat. Wheat protein isolate is also very tolerant to salt and phosphates, which is important because it must act synergistically with activated meat protein in a whole-muscle injected product. Wheat protein generally amounts to between 1% and 2% of the finished product for whole-muscle injected products, and up to 4% in highly extended re-formed brine-added ham products.

Pork rind powder is used to increase firmness of the finished product and to enhance cooking yield. Two types of pork rind powder are used in the production of ham: injectable, which is included in the brine and thus injected directly into the muscle, and non-injectable, which is added to the tumbler.

Ice-cold water must be used to prepare brine containing injectable pork rind powder, as otherwise the particle size of the pork rind powder increases and may block needles and filters. Some degree of shearing or stirring forces are required to disperse the powder evenly within the brine and, if possible, the pork rind powder should be premixed with other additives such as phosphates, sugars or salt first before being added to the ice-cold water. Premixing increases dispersibility significantly.

Non-injectable pork rind powder is added directly into the tumbler either before the tumbling process commences or after the injected meat has been tumbled for several hours. The addition of the material before tumbling commences ensures that the tumbler does not have to be opened during tumbling. A theoretical explanation for the benefits of later addition of pork-rind powder to the tumbler is that the muscular protein will already be activated ready for the addition of another protein. Non-injectable pork rind powder introduced into the tumbler can penetrate much more effectively into the muscle where the injected meat has been knife tenderized rather than needle tenderized (see Section 8.4.3). Whichever method is used, the addition of pork rind powder to a level of 3–10 g per kilogram of finished product (0.3–1.0%) is the norm, with 5 g per kilogram sufficient for a significant increase in firmness.

Starch is also a common additive in highly extended injected ham products and is either included in the injection brine or added directly into the tumbler before tumbling commences. Care has to be taken that the type of starch chosen does not block filters or injector needles, is easy to disperse in water and also demonstrates little sedimentation within the brine itself. Starch added directly into the tumbler can result in lumps within the ham mass which will not dissolve during subsequent tumbling. This is avoided by mixing the starch with some brine and adding the resulting slurry to the tumbler. Starch is commonly applied at amounts of between 10 and 50 g per kilogram of finished product. It holds moisture during heat treatment, forms a gel upon cooling (contributing to texture) and also acts synergistically with activated protein from the muscle tissue itself as well as other gelling non-meat proteins, such as soy.

Carrageenan is another commonly used additive and is used in amounts

between 2 and 7 g per kilogram of product on the basis of *quantum satis*, or as much as needed in order to obtain the desired result. Carrageenan demonstrates enormous WHC, which means that only small amounts are needed to increase the cooking yield. As a rule of thumb, 1 g of carrageenan per kilogram of finished product enhances cooking yield by around 6–8%. The addition of such small amounts has no impact on the colour or taste of the finished product. Carrageenan can, however, have a fairly high microbe count, and very high numbers could have a negative impact on the shelf life of the cooked product. Heat-treated ham products containing carrageenan must not be exposed to any mechanical force whilst still warm, such as squeezing by hand, in order to settle properly and to form a solid gel during the cooling period. Introduction of carrageenan only makes sense in cooked ham products where the product is thermally treated to at least 69–70 °C, as carrageenan is only fully functional (solubilized) at such temperatures and able to form a gel upon subsequent cooling. Therefore carrageenan should not be added to a whole-muscle meat product which is sold in a raw state.

Other hydrocolloids, such as LBG, are generally not added to cooked ham products, because LBG requires heating to around 80 °C to be fully functional and hams generally are not heated to such a high core temperatures. Cold-swelling gums, such as guar and xanthan gum, are commonly added to injected whole-muscle non-cooked products such as roast pork because they hold added water in a cold stage and the final consumer prepares the product at home. The level of guar or xanthan gum introduced into injected meat depends primarily on the viscosity of the brine, as higher inclusion levels of these gums significantly increase the viscosity of the brine. Typically, guar or xanthan gum at levels around 0.3–0.8 g per kilogram of product is introduced into meat products which are sold fresh (uncooked).

Salt is generally present in whole-muscle products at amounts between 16 and 22 g per kilogram of product, but may be outside this range. The main functions of salt are the solubilization of protein and contribution to flavour. Technologically speaking, 12 g of salt in conjunction with phosphates is the minimum amount required per kilogram of product to solubilize protein effectively. Addition rates below 12 g per kilogram of product result in too few salt ions, lowering the repulsive forces between muscle fibres and hence resulting in smaller amounts of solubilized protein. Adding 50 g of salt per kilogram of meat would result in the highest possible amount of solubilized protein but is not acceptable from a taste point of view. The addition of 50 g of salt per kilogram of product, or 5%, would result in 6% total salt per kilogram of meat, because the meat itself already contains around 1% salts (lactate, phosphate, citrate and others). At concentrations of salt above 6%, proteins are denatured by the impact of salt and the WBC of proteins decreases again.

Flavours and flavour enhancers such as MSG or ribonucleotide are commonly added to ham products. They have to be soluble in water (brine) so that they do not block the needles. Colours such as carmine, allura red and

fermented rice may also be added. Colours are generally necessary, once the cooking yield exceeds around 140% because, from this yield upwards, there is a visible and distinctive loss in curing colour, or colour strength, as all the added water dilutes the natural red colour of the meat.

Curing colour is obtained by the addition of sodium nitrite at levels of 150–300 ppm per kilogram, calculated per kilogram of injected meat and not as per kilogram of finished product. The amount of nitrite introduced into the raw injected meat is generally up to twice as much as the amount permitted in the finished product. For example, if 125 ppm of nitrite are permitted per kilogram of finished cooked product, around 180–250 ppm (or 0.18–0.25 g) are introduced per kilogram of injected meat. However, this is a rule of thumb and practical experience will quickly demonstrate how much nitrite can be introduced into the raw injected meat so that the amount in the cooked product remains just below the permitted legal limit. Vast variations are seen worldwide between the amount of nitrite added to injected raw meat and the amount of nitrite found in the cooked product, as there are so many other factors involved during processing, including the presence or absence of a colour enhancer, the myoglobin content of the meat and the calibre of the casing that the product is filled into.

Larger products are thermally treated for a longer period of time and more nitrite is used than for smaller, or small-diameter, products. For example, if 200 ppm of nitrite are added to a ham mass and the same mass is filled into a 60 mm casing or a 160 mm casing, the 160 mm product will require much longer thermal treatment in order to reach the same core temperature as the 60 mm product. Even when the same amount of nitrite is introduced and the same core temperature reached in both products, the amount of residual nitrite in the 160 mm product is likely to be somewhat less than in the 60 mm product, because the prolonged heating for the larger product causes a significant amount of nitrite to be converted into nitrate or simply 'lost'. It is still not possible to identify exactly what happens to all the added nitrite.

Mixtures containing nitrite and salt are commonly used, and, for instance, 2.0 g of a mixture containing 10% nitrite and 90% salt will introduce 200 ppm into 1 kg of injected meat. Those 2.0 g equate to 0.2%, which can be used in the formula given in Section 8.3 to obtain the correct amount of nitrite in a brine solution, calculated according to a predetermined level of injection.

Nitrate is not normally added to cooked ham because the development of curing colour and curing flavour takes place quickly; so there is insufficient time for the nitrate to be reduced to nitrite to develop the curing colour. Colour enhancers in the form of ascorbate or erythorbate are added to ham brines in amounts that result in 0.4–0.8 g (0.04–0.08%) per kilogram of finished product. Ascorbic acid must never be added to a ham brine containing nitrite. When nitrite and ascorbic acid come into direct contact, an instant chemical reaction takes place resulting in the formation of nitrogen oxides ( $\text{NO}_x$ ). The main nitrogen oxides formed are nitric oxide (NO) and nitrogen dioxide ( $\text{NO}_2$ ) which are toxic and a serious threat to human health. As a

result of such a chemical reaction, the nitrite required for the injected meat is lost. Ascorbate does not react with the nitrite in the brine because of the alkaline pH; it turns into ascorbic acid only once it has been injected into the meat, where a pH of below 7.0 (acid environment) provides the right environment for the reaction to take place.

Colour enhancers such as citric acid, other acids and GDL should not be introduced into the brine either, because they lower the pH of the brine and subsequently of the meat product, which reduces WHC and results in a lower cooking yield. Another critical point is that these sour additives are or create an acid and therefore release  $H^+$  ions into the brine, which can react with nitrite. The likelihood of a reaction between these sour additives and nitrite depends largely on the concentration of the acids within the brine, and, if concentrations are similar to those of nitrite, it is probable that nothing will happen. However, such a reaction must be avoided. As long as the pH of the brine is above 8.0 and these additives are introduced at the very end of the brine preparation process (after the salt), nothing much should happen. However, the addition of a sour additive into ham brine is not generally recommended. There are other commonly applied and permitted additives for colouring and enhancing the colour of ham, as well as additives to extend shelf life, which make the use of an acid in brine obsolete. The enzyme TG is occasionally used to increase firmness and to reduce purge in the finished and packed product. The amount of the enzyme-carrier blend used varies and is generally around 0.05% or 0.5 g per kilogram of finished product, depending on the amount of active enzyme present within the blend sold.

Water is added to ham products as a solvent for proteins in conjunction with phosphates and salt, as well as a means to reduce the cost of the finished product. The water used to prepare brine must be of drinking quality (potable) and should not contain chlorine. If ice is not used in the preparation of brine, the water must be at a temperature of 0–2 °C. Hard water can cause problems regarding the functionality of phosphates (see Chapter 6, Section 6.7). Lactate or a lactate-(di)acetate blend is added in order to increase shelf life, especially for products that have a large surface area, such as those which are sliced or shaved. The recommended level of sodium lactate is 30–35 g (or 3–3.5%) per kilogram of finished product, and the amount of salt applied should be reduced by around 1–2 g per kilogram of product to compensate. The sodium from sodium lactate, in combination with the sodium originating from sodium chloride (salt), results in a more pronounced salty taste in the ham than without sodium lactate. This saltier taste can be covered up with a slightly increased level of sugar, but excess levels of added sugar can cause other problems, such as souring if the ham is not properly heat treated. Potassium lactate at 30–35 g (or 3–3.5%) per kilogram of product is used as an alternative, and the amount of salt added to the product can remain unchanged given that potassium chloride does not make the end product taste more salty.

A slight reduction in salt content can cause a reduction in cooking yield because the decreased ionic strength means that protein swelling is also

decreased. However, if other additives, such as carrageenan and proteins, are introduced into the product as well, reducing added salt by 1–2 g per kilogram of product will not result in a significant drop in yield, as those additives bind water very effectively. Acetate is sometimes added to extend shelf life. The addition of around 1–1.5 g of acetate per kilogram of finished product has a small positive effect on shelf life, with no unwanted vinegar-like taste at such low inclusion levels. Shelf life is more commonly extended through the addition of lactate, because it is significantly more effective than acetate added in such small quantities and, when lactate is added, there is no risk of obtaining a vinegar-like taste at all. Lactate also causes a slight increase in cooking yield because it can bind around 60–70% of its own weight in water as it is hygroscopic, whereas acetate has no effect on cooking yield.

Sugars are commonly added to ham and other injected cured and non-cured whole-muscle meat products in order to round up the flavour, to cover up the salty taste, to contribute to the Maillard reaction when the finished and sliced product is fried (for instance bacon) and to add dry matter to increase yield. The typical usage rate is around 5–15 g per kilogram finished product, and the most commonly added sugars are dextrose, sucrose and brown sugar. Brown sugar gives a distinctive taste to the product. Dextrose exhibits a much lower sweetening capacity than sucrose and a greater osmotic pressure in solution; thus greater quantities of dextrose than sucrose can be added without making the product taste too sweet. The impact of sugar on yield is marginal, but sugar does reduce the  $A_w$  of the product, thus contributing to longer shelf life. Generally, sugar is not added to whole-muscle products to lower the  $A_w$  value to establish a microbiological hurdle because whole-muscle products exhibit such a high level of water that the  $A_w$  never becomes an effective hurdle. However, the introduction of sugar extends the shelf life in the sense that the same product without any sugar would demonstrate an even higher  $A_w$ . Care must be taken that ham products containing elevated amounts of sugar are thermally treated to around 70 °C at least to kill bacteria effectively, as sugar is an ideal substrate for any bacteria that survive the cooking process.

Maltodextrin, for instance corn syrup, is also used extensively in ham products for the same reason as sugar, but shows less burning when the sliced product is fried. Maltodextrin is less sweet than sugar and often costs less as well.

SMBS is occasionally used to extend shelf life. No reaction occurs between SMBS and nitrite when they are both present in brine at similar concentrations or when SMBS is present at a lower concentration than nitrite and the pH of the brine is above 7.2. However, having elevated levels of SMBS in a brine containing significantly smaller amounts of nitrite than SMBS can cause the nitrite to be 'removed' from the brine. In chemical terms, when there are two equal reactants present in the same system (e.g. brine), the reactant present at a much higher concentration forces the other reactant out. In this case, nitrite would be lost and the finished product would have poor curing colour

(if any develops at all) and also no curing flavour. When the pH is below 7.0, sulphur dioxide ( $\text{SO}_2$ ) is generated in the meat after injection and released from SMBS. SMBS acts as a preservative in the ham product only up to the point when the ham is cooked. During the precooking period (injection, tumbling and filling), SMBS keeps bacterial growth under control but, once the ham is cooked, and all protein is denatured and water is immobilized, SMBS no longer acts as a preservative because it requires free water for the release of  $\text{SO}_2$ .

As pointed out earlier, the type and amount of additives used are determined by the injection rate and the expected cooked yield of the product. Higher cooked yields require highly effective functional additives, such as carrageenan, proteins and starch. It is unwise to inject whole-muscle meat with, for example, 70% brine while adding only phosphates and salt because these two additives on their own are unable to hold, or bind, all the water introduced. In such cases, unnecessary weight in the form of water is carried through the entire manufacturing process and then lost during thermal treatment. Where waterproof casings are used for the production of ham and no separation of water is allowed during thermal treatment, the type and amount of additives must be chosen in such a way that the finished product shows no separation of water despite the normally occurring variations in the quality of the raw material.

Generally, all additives in the brine must have a small enough particle size to ensure that they do not block the needles or filters during the injection process. A good measurement of injectability is that the finished brine should pass easily through a filter with a grid size of 0.5–0.6 mm, which is fine enough for most injectors. Fish and poultry require finer needles, and the particle size of the additives must be adjusted accordingly to avoid blockage.

### **8.2.1 Theory of protein swelling and activation of protein**

The processes of protein swelling and solubilization are extremely important for all meat products where water, and water and fat, are introduced and some form of binding or fat emulsification is required. The swelling and solubilization are linked and require added water. Only solubilized protein can act as an emulsifier in fat-containing products while at the same time immobilizing large amounts of added water.

At the IEP (pH 5.2 in muscle meat), most proteins are present in their ionized form and exhibit the  $\text{COO}^-$  and  $\text{NH}_3^+$  configuration. Opposite charges are attracted to each other and so the protein is tightly bound together. At this stage, WHC and solubility of the protein itself are at their worst and the capillary effect is at its weakest. The addition of phosphates and salt plays a vital role in the process of protein swelling and activation. The onset and completion of rigor mortis includes the establishment of cross-links between actin and myosin, and these links limit the degree of swelling. Phosphates

remove the cross-links and therefore permit effective swelling of the fibrous protein structure.

The addition of salt enhances ionic strength. The added  $\text{Na}^+$  and  $\text{Cl}^-$  ions act as a separating force because they bind to the protein side chains and increase the repulsive forces between them, thus establishing swelling by increasing the gaps between actin and myosin. Water then penetrates into the opened, or widened, protein structure and creates even larger gaps between actin and myosin. This process, known as protein swelling, continues to the point where the fibrous structure of the muscle tissue cannot be maintained any longer. At this point, the highly swollen fibrous muscle structure turns into a viscous or liquid form. This is the final stage of swelling and is known as protein solubilization. In one respect, phosphates added to meat products perform the same function as ATP in the living muscle by separating actin from myosin.

The degree of protein solubilization is increased by mechanical forces during processing, for instance cutting, mixing and tumbling, because the mechanical energy supports the bursting of tightly swollen protein molecules. It is important to remember that phosphates on their own hardly activate protein at all; they only remove the link between actin and myosin. Similarly, salt on its own causes swelling of the protein structure but does not solubilize much protein. When both additives are applied together, they act very strongly in a synergistic way and large amounts of protein are solubilized.

Solubility and WBC of proteins in meat in general is enhanced at higher pH values because some form of maturing has taken place, and in meat originating from young animals because fewer cross-links between actin and myosin are present compared with muscle tissue from older animals. Additives such as citrate and other salts of organic acids only enhance the ionic strength and support swelling of the fibre structure but do not remove the cross-links between actin and myosin in the same way that phosphates do. As a result, the combination of citrate and salt is far less effective at solubilizing protein than the combination of phosphates with salt.

### 8.3 Calculating brine composition and injection levels

A brine is a mix that contains all required additives in water and is frequently referred to as the pickle, marinade or cure. All additives in the brine must be at the correct concentration for the desired level of injection and, more importantly, cooking yield. Within meat technology, the term cure refers to a blend of additives without water, but in real life the term cure is used interchangeably with brine, which can be confusing at times. The basic formula used to calculate the percentages of additives in a brine is

$$\text{CB}\% = \frac{\text{CP}\% \times \text{Y}\%}{\text{IR}\%}$$

where CB is the concentration of an additive in the brine, expressed as a percentage, CP is the concentration of an additive in the finished product, expressed as a percentage, Y is the weight of finished product, expressed as a percentage based on the green weight (weight of untreated meat; the green or starting weight equals 100%) and IR is the injection rate of brine into the raw meat, expressed as a percentage.

In order to calculate the percentage of an additive in a brine, the usage rate of the additive in grams per kilogram has to be converted to a percentage. For example, if the amount of phosphates present in the finished product should be 5 g per kilogram of product, then those 5 g equal 0.5%.

### 8.3.1 Theoretical example for a brine

Whole-muscle pork ham is to be produced using 100 kg of raw material, which represents 100%. The level of injection is 45%, which results in 145 kg of injected meat (145%). After tumbling, the mass is filled into a fibrous (water-permeable) casing, smoked and steam cooked.

For a product filled into a fibrous casing, the weight after the drying, smoking and cooking process will be around 135 kg, which equals 135% cooking yield. From an additive point of view and for calculation purposes only, salt should be present in the final product at 18 g (1.8%) per kilogram of finished product, phosphates at 5 g (0.5%) per kilogram of finished product and carrageenan at 4 g (0.4%) per kilogram of finished product.

### 8.3.2 Calculation

If 100 kg of meat equal 100% and injection will be 45%, then 145 kg of injected meat is obtained ( $100 \times 1.45 = 145$ ). A brine, based on a 45% injection and 135% cooking yield therefore has to contain

$$\text{CB(salt)} = \frac{\text{CP}(1.8) \times Y(135)}{45}$$

$$= 5.4\%$$

$$\text{CB(phosphates)} = \frac{0.5 \times 135}{45}$$

$$= 1.5\%$$

$$\text{CB(carrageenan)} = \frac{0.4 \times 135}{45}$$

$$= 1.2\%$$

Therefore, the total brine for a 45% injection, based on 135% cooking yield, should contain 5.4% salt, 1.5% phosphates, 1.2% carrageenan and the remainder (to make up to 100%) will be iced water, in this case 91.9%. By injecting

such a brine at 45%, the level of each additive in the finished cooked product will be as predetermined by the calculations.

Alternatively, if the tumbled meat is filled into a waterproof (non-permeable casing) and therefore the product does not experience any loss in weight during thermal processing, the figure for cooking yield in the formula will be 145% instead of 135%, as 45% is injected and no loss is obtained.

The brine commonly contains a mixture of different additives and the required amount of a compound (premix) in grams per kilogram of finished product has to be converted into a percentage in order to use the calculation above. For example, if a mixture of additives contains phosphates, nitrite, flavour, carrageenan and soy protein and the finished product must contain 50 g of this premix per kilogram of product, which is 5%, then the value 5 is used in the calculation. The addition of a single compound simplifies the calculations of a brine, as only that and the salt have to be calculated, with water making the total up to 100%.

Suppliers of ingredients should be able to describe the composition of a brine exactly, based on predetermined levels of injection and cooking yield. Calculating the brine correctly is extremely important. Insufficient levels of additives in the finished product can cause an economic loss, because desired cooking yields and slice coherency are not obtained. On the other hand, adding excess additives is a waste of money. The correct level of nitrite in a brine is particularly critical, because there are strict rules regarding the maximum level of nitrite permitted in the finished product. Insufficient nitrite results in problems with colour and colour stability while too much nitrite, above the legal limit, creates a legal problem.

Manufacturers often produce different types of ham with similar levels of injection, and the same brine can be used in different amounts to simplify the process. A brine prepared for a low level of injection, for instance 15–20%, means that concentration of additives in the brine is high. However, such concentrated brines cannot be used for largely varying injection rates, as there is a huge difference between a brine made for a 20% injection and that for a 30% injection. It is a common misunderstanding that injecting 30%, instead of 20%, is a difference of just 10%. Based on a desired injection rate of 20%, and viewing that 20% as 100%, an injection of 30% is 50% more. A ham injected at 30% using a brine made for a 20% injection will contain excess levels of salt, phosphates and especially nitrite in the finished product.

More diluted brines can be used for slightly varying levels of injection because the concentration of additives in the brine is much less than for low-injection brines. For instance, a brine prepared for a 60% injection can be used for 55% and 65% injections as well and there will be no significant disadvantage to the final product. However, if it is important that the exact amounts of each additive should be present in the finished product, then the brine should be prepared according to those parameters.

## 8.4 Manufacturing technology

Manufacturing technology turns meat materials and additives into the desired finished product. Machinery plays a vital role, but there are several other technological aspects that must be considered as well.

### 8.4.1 Preparation of brine

Preparing the brine correctly is vital for the colour, cooking yield, shelf life and slice coherency of the finished product. A brine is a suspension consisting of soluble and insoluble materials dispersed or dissolved in water.

The optimal temperature of a brine should be between  $-2$  and  $2$  °C, once all required additives are dissolved or dispersed within it, and temperatures below and up to  $0$  °C are optimal. Low temperatures reduce the risk of a rise in temperature during the tumbling or mixing process, which reduces the risk of bacterial growth in the injected meat. This is important because injected meat contains much free water and nutrients such as protein and sugar, which favours bacterial growth. In addition, the optimal solubility of the fibres actin and especially myosin (which is by far the most important salt-soluble protein) lies at around  $0-3$  °C.

The temperature of the brine is kept low by using chilled water or cold tap water containing ice. If ice is used, then approximately half the total amount of ice is added to the water first, before any additives, so that the water is cold when brine preparation begins. Tap water can be slightly warm in tropical countries or during summer, and the ice reduces the temperature to around  $6-10$  °C, which still permits excellent solubility and dispersibility of additives. Generally, additives such as phosphates, sugar and salt are much more soluble at these temperatures than at the lower temperatures ( $0-2$  °C) that would result from using ice-cold water from the beginning. However, specialized blends of phosphates also dissolve readily in ice-cold water. Once all additives are completely dissolved and/or dispersed, the remainder of the ice is added to cool the brine even further. No ice must be present during the preparation of the brine as the additives would stick to the surface of ice particles and freeze, losing their functionality. Modern brine tanks cool water using propylene glycol or other materials, and heat exchangers are also utilized for obtaining ice-cold water. Another common method for obtaining cold water, although only practicable in smaller operations, is to have a water tank placed in the chiller and to cool the water overnight.

The sequence in which the additives are added to the cold water is important as well. Those that dissolve, such as phosphates, sugar and salt, should be added before those that disperse, such as starch and carrageenan. Assuming that individual additives are used, the phosphates should always be added first because they require a large volume of free water to dissolve completely. The mixture should be stirred until the phosphates are fully dissolved, which takes around  $2-5$  min depending on the intensity of stirring or mixing. Once the phosphates are dissolved, part of the water required for dissolving them

is released again. Salt must never be added before phosphates, as the amount of water bound by salt is high and insufficient free water would be available to dissolve the phosphates, especially in highly concentrated brines used for low levels of injection. There are some exceptions because highly salt-tolerant phosphates are available for specialized applications but, as a general rule of thumb, phosphates should be added to water before the salt.

Once the phosphates are completely dissolved, materials such as sugars and injectable protein (mostly soy isolates) are added and the brine is mixed well. Salt is added next and then starch or carrageenan if required. Adding the salt reduces the surface tension of water and therefore enhances the dispersibility of carrageenan and starch. The level of salt within a brine is generally four times that of phosphates, so that around 20 g of salt are applied per kilogram of meat product compared with around 5 g of phosphates per kilogram of meat product.

Thus, for a brine containing just phosphates, carrageenan and salt (no protein or starch), the correct sequence based on solubility and dispersibility would be phosphates → salt → carrageenan. However, experience shows that, if the carrageenan is added before the salt and the mixing involves some form of shear, all the additives will disperse and dissolve well.

Newly developed and very specialized soy isolates demonstrate a slightly better functionality if added to the brine after the salt. If soy is added, the brine should be mixed for at least 10–15 min to hydrate the soy protein fully and thus to make it fully functional. Overmixing should be avoided as it is of no advantage. The presence of soy protein in brine can lead to the formation of foam if the brine is mixed for a long period of time using a high-speed stirring device. Placing the stirrer in the centre and near to the bottom of the brine tank can reduce, or eliminate, the formation of foam. Using ice-cold water from the start also suppresses foam formation. If an antifoaming agent is used, then it should be added to the brine before the salt, but this is generally not needed and, if a brine is mixed for around 20 min with a proper stirring device, foaming generally is not a problem.

Some additives can be premixed to enhance dispersibility and to simplify brine preparation. Premixing sugar with carrageenan, soy protein or starch enhances dispersibility greatly, which is of benefit because dispersibility of starch and soy in ice-cold water can be a problem. The process is simplified as phosphates are added first, followed by blends of soluble and dispersible materials and finally salt. The simplest method of preparing a brine is to use a compound, or complete blend, containing all the additives required except salt. Mixing for 5–10 min is sufficient to dissolve or disperse the additives before the addition of salt, and mixing for another 5 min completes the process.

The brine should be prepared shortly before or on the same day that it is used because some of the additives break down over time. For instance, phosphates break down into monophosphates, which will not act on the protein. This would result in the activation of no, or very little, protein during the tumbling or mixing process and the cooking yield and slice coherency

would suffer dramatically. A slight distinction should be made between a brine that has not yet been used for injecting meat and one that has. Freshly prepared brine can be stored overnight in the chiller at 0–4 °C and used the next day without any significant negative impact on the finished product. However, the brine will have to be mixed again before use as materials such as carrageenan, soy and starch will have settled overnight.

Brine that has already been used for injecting meat is contaminated with traces of blood, proteins, enzymes and other materials. These contaminants provide ideal substrates for bacterial growth, which could affect shelf life, colour and flavour of the finished product. Thus brine for reuse must be stored at low temperatures, around 0 °C, and kept for as short a time as possible.

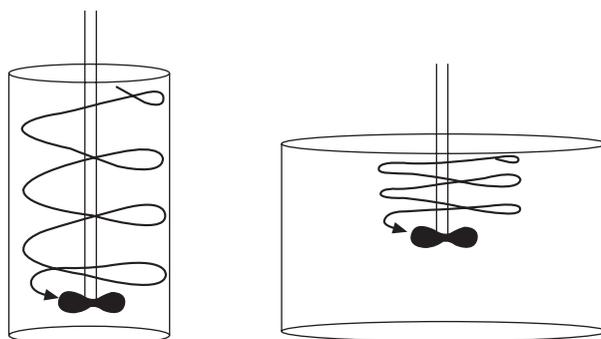
The viscosity of the brine must be controlled to prevent the equipment (pipes, hoses, pumps, tubes, filters and needles) from becoming blocked. The addition of small amounts of cold-swelling gums to the brine, for instance guar or xanthan, reduces or delays the sedimentation of additives such as carrageenan, soy protein and starch. Sedimentation can also be prevented by agitating the brine regularly. Sedimentation is a problem because it results in an unevenly mixed brine and thus a non-uniform product, which can lead to shortfalls in parameters such as cooking yield, colour and slice coherency. Care must also be taken to avoid sedimentation if brine is prepared in a large tank and then pumped to smaller holding tanks.

The use of a salinometer (salometer) in preparing brines is generally not recommended because it measures the salinity of a solution containing salt and water by measuring the density. Since brine generally contains several other substances that affect the density, the salinometer will only measure the density and not the salinity of the brine. However, it is still common practice to measure the finished brine with a salinometer and to record the reading. This method of checking brine is not beneficial because different compositions can have the same density. It is far better to prepare brines according to the weights in kilogram of the additives.

If a modern brine mixer is not available, it is better to use a container with a small diameter than one with a large diameter. The stirring device should be installed close to the bottom and in the centre of the container in order to obtain a sucking and/or twisting effect. If the container has too large a diameter and the stirring device not placed correctly, the brine will not be mixed well and some sedimentation of materials will occur. Brine tanks should be smooth in shape so that additives do not become trapped in corners as this results in uneven mixing. Figure 8.1 shows the differences in effectiveness between a small container and a large container.

#### **8.4.2 Injection of the brine**

Injection is the process whereby brine is mechanically introduced into muscle tissue. All additives should be introduced evenly and in the proper concentration into all parts of meat being processed. Injection technology has advanced



**Fig. 8.1** Difference between a small-diameter container with a correctly proportioned stirring device and a large-diameter container with a stirring device which is ineffective at the sides and bottom of the container.

greatly in the last few years and levels of up to 70–90% can be injected easily in one pass. Great care must be taken to keep the injector and all other pieces of equipment clean and functioning properly. The needles require special attention and must be sharp, clear of blockages and free of rust or any other foreign material.

There are several different methods of injection. Some injection systems constantly chill the brine and prevent any increases in temperature. Spray injection needles have a series of holes starting at around 10–15 cm from the sharp end and, once the needle has completely penetrated the piece of meat, brine is injected and distributed predominantly horizontally in a single blow. Other systems inject brine into muscle tissue while being pushed into the meat as well as when fully inserted, and some only inject brine during insertion. All systems have advantages and disadvantages.

The diameter, or thickness, of the needles depends primarily on the type and cut of meat to be injected; for instance, poultry requires thinner needles than those used for beef, and very fine needles are needed for fish. The entire needle head can be exchanged easily on modern injectors in order to switch from meat injection.

The level of injection and expected cooking yield of the product must be as accurate as possible because they determine the composition of the brine (see Section 8.3). If excess amounts of brine are introduced, then the levels of phosphates and other additives will be too high in the final product, resulting in unnecessary cost, impaired taste and possibly legal problems if the maximum permitted level of residual nitrite is exceeded. If too little brine is injected, then levels of additives will be too low, resulting in lower cooking yield, shorter shelf life and impaired flavour. Insufficient nitrite in the finished product results in a weak and unstable curing colour. If the amount of brine injected is only slightly below the target, the missing amount can be added directly to the tumbler, or during extension prior to tumbling for re-formed whole-muscle products. The amount of brine added directly to the tumbler can be between 4% and 8%, depending on the type of tumbler

used, whether the meat was membrane skinned or not and whether the meat was tenderized. Injected meat that has been knife tenderized and membrane skinned can absorb, or immobilize, higher levels of added brine because of the greater muscle surface. Meat that has not been membrane skinned or tenderized can absorb only around 2–5% of added brine during tumbling.

Highly extended products absorb less added brine at the tumbling stage, because the muscle is already swollen and cannot absorb much more. For example, adding a further 10% to highly injected meat, say 80%, may result in absorption, but almost all the extra brine will be lost during subsequent heat treatment. Adding brine in the tumbler commonly gives the impression that additional brine has been absorbed, but there is a large difference between brine absorbed by muscle tissue during tumbling and brine that is properly bound within the muscle tissue. Not only is the brine absorbed during tumbling generally lost during the subsequent heat treatment, but also it can cause problems in packed, or sliced and packed, products owing to excess purge formation. Therefore the addition of brine to whole-muscle products in the tumbler should be kept to a minimum, and the full level of extension should be achieved through injection. If the process of injection is interrupted for a prolonged period of time, the injector should be flushed or rinsed with water to remove materials that may have accumulated in needle heads or pipes. Once injection of meat commences again, the rinsing water must be flushed out completely with brine, to make sure that the meat is not injected with plain water. The brine in the tank should also be stirred before injection recommences, unless the tank is stirred constantly, to ensure that the brine mix is homogeneous.

The injection pressure should not exceed 1.5–2 bar or 22–28 p.s.i. If a higher pressure is applied, there is a greater risk of destroying the muscle fibre structure, which would mean that pockets of gel would be visible between the individual fibres in the final product. However, latest developments in injection technology allow higher injection pressure without destroying the muscle fibre structure. Poultry meat is very sensitive to the formation of gel pockets owing to its soft fibre structure. The injection pressure must also be adjusted according to the fat content of the meat. More fatty meat, such as pork belly and pork neck, is injected at a lower pressure, around 1.0 bar, because the layers of meat and fat present in such cuts are easily blown apart.

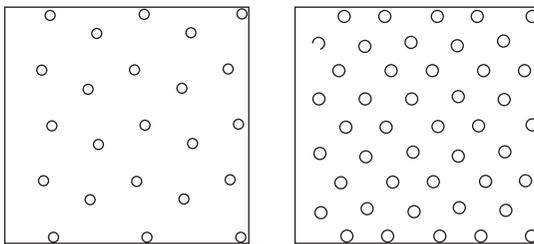
If injecting at 1.5–2 bar does not result in the desired weight gain after one pass, injection can be repeated, although handling the meat for a second time is uneconomical. Double handling can be avoided by having a second injector. Some injectors have two needle heads on the same machine and perhaps hundreds of needles in each needle head, depending on the size of the injector, and thus double injection can be achieved in one machine in one pass. The injection pressure can be kept lower by operating two single-head injectors in sequence or a double-head injector because the total level of injection can be divided into two injection steps. This introduces the brine more gently into the muscle tissue, avoiding damage to the fibre structure.

Another way to inject high levels of brine in one pass without increasing injection pressure is to slow down the belt on the injector, so that the needle head comes down more often on each piece of meat. This has the additional benefit of ensuring that the additives are more evenly distributed. Raising the stroke rate of the needle head, which can be achieved easily on most modern injectors, is yet another method of increasing the amount of brine injected into meat without increasing the injection pressure; it also serves to increase grid density. Figure 8.2 shows different injection grids depending on stroke rate of the needle head and the speed of the belt.

Modern injectors can easily inject 40–70% in one pass without destroying the muscle fibre structure. They can also measure the size of large pieces of meat to be injected individually using lasers and the predetermined injection rate is reached precisely, regardless of the shape and size of each piece of meat. For an entire deboned pork leg to be injected with fat and skin still on, the opened legs should be placed on the belt with the skin side down (on the belt). The needles must be adjusted frequently to ensure that they do not penetrate too far. More specifically, the needles must stop at around 1.0–1.5 cm above the belt; otherwise brine is injected between the meat and the layer of fat and large gel pockets will be visible in the cooked product.

In highly extended whole-muscle products, which are 70–100% injected, an additional 5–10% of minced lean meat (3–4 mm blade) based on the total weight is frequently added in the tumbler. Adding lean minced meat improves slice coherency and the firmness of highly extended products but is only effective if the injected meat has been well tenderized as minced meat mixes well with well-tenderized whole-muscle tissue.

After use, all pipes, tubes, valves, filters and needles on the injector must be cleaned properly and checked for blockages. Using a dirty machine to inject meat will result in faulty products, with poor shelf life, colour, colour stability, flavour and slice coherency. Once the machine is thoroughly cleaned it should be disinfected, taking care to use the correct concentration of disinfectant. If the injector is not cleaned and disinfected properly, bacteria can (and will) grow on and under the belt, in the tubes and hoses, and in the injector needles. All machinery must be rinsed thoroughly with clean water to remove all traces of cleaning and disinfecting materials, which will otherwise affect subsequent products. Most cleaning materials are highly alkaline and



**Fig. 8.2** Different injection grids.

also demonstrate a strong oxidizing effect and will negatively affect curing colour and taste of any products contaminated with them.

Needles must be kept free of blockages. Even when cleaning-in-process procedures are in operation, the needles must be removed from the injector at regular intervals and placed in a solution containing fat- and protein-releasing agents, or vinegar, overnight, and then flushed well the next day. Coca-Cola can be used for this because it contains phosphoric acid and has a low pH; so it loosens up particles of protein and fat during soaking and is easily flushed out with warm water. Most often, needles are flushed under pressure.

Needle-free injection using nozzles to fire a beam, or shot, of brine into meat is being tested for whole-muscle products. The highly concentrated beam penetrates the meat and introduces the additives required. The advantage of such an injection system would be that contamination during injection would be totally eliminated. However, there are still some problems with this method that must be solved before it becomes commercially useful. Current shortfalls include the need to keep the meat still while the shot of brine is injected, and different levels of injection for unevenly sized pieces of meat.

Ham-on-the bone products are occasionally artery pumped. Around 10–15% of highly concentrated brine, generally containing phosphates, salt, nitrite, sugar and colour enhancer, is injected in front of the branch in the femoral artery so that the brine goes into every area of the leg. Brine can also be injected into each branch, which results in even better brine distribution. After injection, the pieces of meat are placed in a soaking brine for up to 3 days before being smoked and thermally treated. Artery-pumped legs often exhibit a 1–2% higher cooking yield than multineedle injected legs.

### 8.4.3 Tenderizing

Tenderizing the injected meat supports cooking yield, slice coherency and firmness in the final product. The most common methods of tenderizing use needles or blades (knives). With needle tenderizing, an extra set of needles penetrates the injected meat, introducing small vertical cuts into the muscle and enlarging the muscle surface. The tenderizer needle head is often a part of the injection machine itself, and the tenderizing needles are sharpened at an angle for easy penetration. Tenderizing needles do not have holes.

Blade or knife tenderizers have two counter-rotating sets of cylindrical blades through which the injected meat passes. The blades cut the meat to varying depths. The degree of tenderization can be adjusted by adjusting the depth to which the blades penetrate the meat. For extremely tenderized meat, applied when extension is high, the tenderizer blades almost cut the pieces of meat apart. Where only a light degree of tenderization is required, the knives only cut into the meat to a depth of 2–4 mm. As a general rule of thumb, the depth of the cut during tenderization correlates to the level of injection. Higher levels of injection commonly require deeper cuts to create more surface area and to allow greater amounts of protein to be activated. If

lean minced meat is to be added during tumbling, for instance to highly extended products, the injected meat should be well tenderized first so that the minced meat mixes well with tenderized larger pieces of meat.

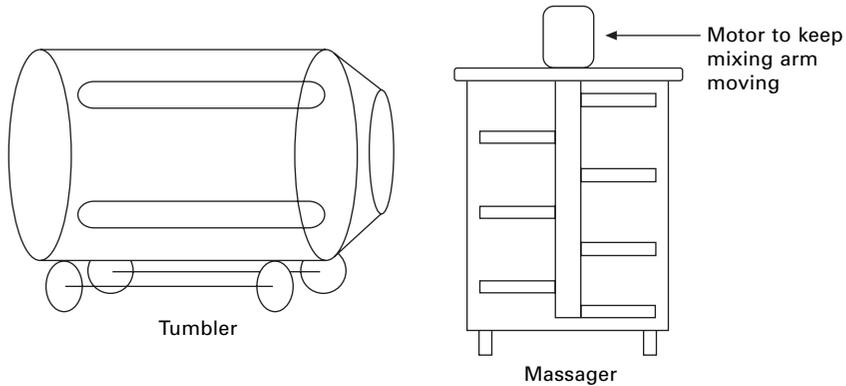
The effect of both tenderizing methods is to increase the surface area of the injected meat, which positively affects the activation of protein during tumbling. It therefore improves cooking yield and slice coherency in the cooked product. Blade tenderizing is more effective than needle tenderizing, and blade tenderizing results in around 3–10% higher cooking yield on average than non-tenderized injected meat. Increased levels of activated protein not only contribute positively towards slice coherency and cooking yield but also significantly reduce the amount of purge in sliced and vacuum-packed finished products. Insufficiently injected meat that has been tenderized absorbs more of the extra brine added to the tumbler during tumbling owing to the enlarged surface area.

#### **8.4.4 Tumbling and mixing under vacuum**

Tumbling is widely used in the manufacture of re-formed whole-muscle products as well as for large products made out of an individual muscle, such as beef silverside. It improves cooking yield, colour development, firmness and slice coherency (for re-formed products) in the finished product. Generally speaking, tumbling always increases the cooking yield of injected meat compared with injected meat that has not been tumbled.

The aim of tumbling is to activate, or solubilize, intramuscular protein, which improves cooking yield, firmness and texture as well as creating a layer of activated protein on the surface of the meat, which is responsible for slice coherency in the cooked product. More specifically, the sarcolemma surrounding the tightly swollen muscle cells is destroyed by the impact of energy from tumbling and solubilized myofibrillar proteins are released. A healthy balance has to be found between the level of injection and amount of tumbling. The higher the level of injection, the more mechanical treatment is required.

The basic principle of tumbling is that the baffles inside the tumbler move the injected pieces of meat up the wall of the tumbler. Once the pieces of meat reach a certain height, gravity causes them to fall. As the meat moves up the tumbler, the pieces rub against each other and the associated pressure causes the activation, or bursting, of the highly swollen muscular protein cells. The kinetic energy of falling released when the pieces of meat land at the bottom of the tumbler also serves to activate protein. The terms ‘massaging’, ‘tumbling’ and ‘mixing’ are commonly used interchangeably but, in tumbling, the container (or barrel) revolves around its own imaginary axis and has no paddles inside whereas, in mixing, the container is stationary and mixing arms, or paddles, move inside it. The term ‘massaging’ is used worldwide and generally means mixing, but is also used to refer to tumbling. Figure 8.3 shows the difference between tumbling and mixing.



**Fig. 8.3** A tumbler resting on rotating wheels, and a mixer-massager.

Experience demonstrates that tumbling is more beneficial than mixing for whole-muscle ham products, because most mixing machines tend more or less to tear the pieces of meat apart. However, there are some newly developed mixing machines that can be used for re-formed whole-muscle products without tearing the individual muscles apart.

The speed of tumbling, or tumbling revolutions per minute, is around 4–6 rev/min in large tumblers and around 7–10 rev/min in small tumblers. If the tumbling barrel turns too quickly, the temperature of the meat mass can rise quickly and, if it rises above 5–7 °C, bacteria will grow. Fast tumbling also increases the amount of rub-off, a fine paste produced when pieces of meat rub against each other at elevated temperatures for a prolonged period of time. The rub-off remains visible between the individual pieces of meat in the finished product and is not attractive to the consumer. Rub-off also affects slice coherency and is visually similar to foam, although not the same.

If tumbling is carried out in a chiller without direct cooling, the optimal room temperature is between –2 and 0 °C, which maintains a temperature of around 0–4 °C in the tumbled meat. Low temperatures are essential and must be maintained during tumbling because the solubility of myosin, and partly actin, is at its very best at these temperatures. Keeping the temperature low is also important to prevent bacteria from growing. Bacteria metabolize proteins, fat and carbohydrates, and the metabolic by-products can affect the flavour, colour and packaging of the finished product. Some bacteria, such as heterofermentative *Lactobacillus* spp., also produce gas by fermenting the sugars present in the meat if the temperature is favourable, and this gas can create small air pockets in the muscle tissue that are visible in the finished product.

If tumbling must be carried out at higher speeds, cooling methods must be used to keep the temperature of the meat low. One method is to have an outer jacket on the tumbler containing material such as propylene glycol, or ammonia. These double-jacket tumblers have the advantage that the optimal temperature can be maintained without placing the tumbler in a chiller.

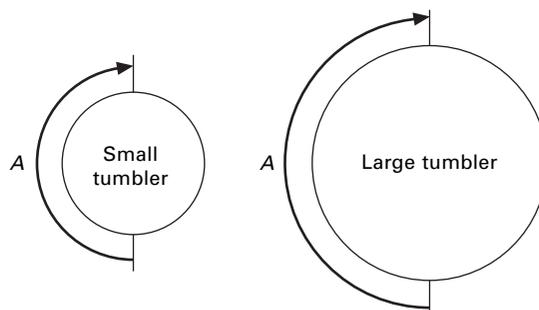
Another cooling method sometimes used is to introduce a cryogenic gas, such as carbon dioxide (CO<sub>2</sub>) or nitrogen (N<sub>2</sub>), into the tumbler. CO<sub>2</sub> must not be applied for a prolonged period of time because it reacts with water from the meat and forms carbonic acid (CO<sub>2</sub> + H<sub>2</sub>O → H<sub>2</sub>CO<sub>3</sub>). Carbonic acid could lower the pH of the meat mass, resulting in a slightly reduced WBC and lower cooking yield. However, carbonic acid is a very weak acid, and considerable amounts would be needed to lower the pH. N<sub>2</sub> is an inert gas and can be added directly to the tumbler without any risk of reaction with the meat. N<sub>2</sub> has a very large cooling capacity because it boils at -196 °C and removes a great deal of heat energy from the meat during evaporation. Care must be taken to ensure that the N<sub>2</sub> does not freeze the meat, because it is very difficult to raise the temperature of the meat mass again for further treatment.

The length of time taken for tumbling depends on a number of parameters, including the following.

- 1 *Filling level of the tumbler.* The tumbler should be between 60% and 80% full based on total capacity, and the best tumbling effect occurs at a filling level of around 75–80% of total capacity. If the tumbler is too full (overloaded), the individual pieces of meat do not rub against each other and the pieces do not have space to fall. The entire meat mass is just turned around and the individual pieces of meat do not experience much mechanical force. Small amounts of protein will be activated and cooking yield and slice coherency will be impaired. If the tumbler contains too little meat, the rubbing effect is lost, again resulting in low cooking yield and poor slice coherency. Consistent tumbling effects can only be achieved by having consistent filling levels for each batch.
- 2 *Types of baffle inside the tumbler.* Different tumblers have different types of baffle inside the container. Some are gentler on the meat while others are more aggressive. The more gentle the baffles, the longer tumbling time is required. Soft meat such as poultry requires gentle baffles so that the cuts of meat are not torn apart.
- 3 *Type of meat.* The fibre structures and hardness vary between different types of meat and even between different cuts of meat from the same species. For example, topside has a much softer fibre structure than silverside, and chicken thigh meat is much harder in texture than chicken breast meat. Generally, chicken is the softest meat, followed by veal, turkey and pork, with beef being the hardest. The tumbling process has to be optimized so that sufficient energy is introduced into the meat without destroying the muscle structure or over-tumbling the material. Hard-textured meat requires longer tumbling than soft-textured meat to obtain comparable amounts of activated protein.
- 4 *Level of injection.* A longer tumbling time is needed when injection levels are high in order to immobilize the larger volume of brine in the meat. At an injection level of 40–60%, tumbling at around 4000–5500

rev will be needed. Over-tumbling must be avoided because it results in a very rubbery and elastic (gummy) texture.

- 5 *Size (diameter) of the tumbler.* The diameter of the tumbler plays a critical role in calculating the amount of tumbling required. The distance that the meat travels in the tumbler before it falls is almost half the length of the circumference, and the meat travels this far on every single tumbling revolution. Because tumblers vary in size, this distance multiplied by the total number of tumbling revolutions, say 4000 rev, can result in a huge difference in distance travelled by the meat. If tumbling processes are to be compared, the total distance travelled by the meat has to be very similar or even the same. Larger tumblers require fewer tumbling revolutions in order to obtain a comparable tumbling effect to a smaller tumbler. For example, say 4000 rev are applied to two batches of injected meat. The diameter of one tumbler is 2 m, which results in a circumference of 6.28 m ( $2\pi = 2 \times 3.14$ ). The meat inside the tumbler moves from the bottom of the barrel up to the top and then falls. The distance travelled is therefore half the circumference, or 3.14 m. After 4000 rev, the distance travelled by the meat is 12560 m ( $3.14 \times 4000$ ). For a tumbler with a diameter of 3 m and therefore circumference of 9.42 m, the meat will travel  $4.71 \times 4000 = 18\,840$  m. This is almost 50% more than the distance travelled in the smaller tumbler. In order to compare the two tumblers, the number of revolutions for the larger tumbler must be reduced to 2666 so that the distances travelled are similar in both. Figure 8.4 shows tumblers of different size and *A* indicates the distance travelled by the meat.
- 6 The total time available for the entire process of tumbling. The total time available including tumbling and resting times plays a role as well. Longer periods of tumbling allow time for the protein to swell and muscle cells to burst. However, tumbling should not last longer than 14–16 h, as the machine would be occupied for too long tumbling a single batch. Practical experience also shows that the tumbling barrel should not be completely horizontal, and an angle between 5 and 15° is ideal.



**Fig. 8.4** The difference between the diameters of a small tumbler and a large tumbler, resulting in different distances *A* travelled by meat during tumbling.

Modern tumblers complete the tumbling process in 5–6 h. The meat is tumbled at temperatures of around 8–10 °C for the first 1–1.5 h in order to speed up colour development. The meat is then cooled to around 0 °C for the remaining 4–5 h using glycol or ammonia in the outer wall of the tumbler. Other modern tumblers have internal baffles that not only turn the pieces of meat upside down but also move the entire meat mass horizontally back and forth in the tumbler during tumbling. This double motion reduces tumbling time by around 30–50%.

There are different methods for tumbling based on the number of tumbling revolutions required.

- 1 *Continuous tumbling.* For this method, the meat is tumbled under full vacuum at a very slow speed, generally 2–4 rev/min, over a period of 12–16 h until the desired number of tumbling revolutions is reached. After tumbling is finished, the meat is processed straight away. As the tumbler turns continuously, great care must be taken to keep the meat cool, as a rise in temperature above 7 °C early in the tumbling process would provide a long time for bacteria to grow, and there would be a large amount of rub-off as well. Once tumbling commences, the temperature of the meat mass should be between approximately –1 and 2 °C, and the temperature during the entire tumbling process should never exceed 5 °C.
- 2 *Split tumbling.* Injected meat is tumbled continuously under vacuum at a slow speed until around 50–70% of the total tumbling revolutions have been completed; it is then removed from the tumbler. The tumbled meat is placed in the chiller to ‘rest’ overnight and then is tumbled again the next morning. During the resting period, the slightly damaged muscle cells swell and burst while the non-damaged cells have plenty of time to swell. The second period of tumbling continues until the remaining 30–50% of the total revolutions are completed. Split tumbling has the advantage that the tumbler is occupied only for a short period of time and the same machine can be used to tumble another batch overnight, thus increasing overall tumbling capacity. Limited tumbling capacity is a common bottleneck in the production of whole-muscle products. Between tumbling sessions the meat must be kept at or below 4 °C. The meat is often placed in large containers between sessions, and enough cooling time must be allowed to ensure that the core temperature of the meat is reduced sufficiently, especially as the semitumbled meat may have been warm (above 5 °C) when it was removed from the tumbler. It can take a considerable amount of time (hours) to reduce the core temperature of the tumbled meat mass to below 4 °C. During this extremely long cooling process, bacteria can grow and, in extreme cases, the meat can sour. CO<sub>2</sub> is commonly introduced into the tumbler for around 1–2 min before the meat is removed, to reduce the temperature of the meat to between 0 and 2 °C before it is taken out of the tumbler. The cooking yield of split-

tumbled meat is generally slightly less than interval-tumbled meat (see below).

- 3 *Interval tumbling.* Interval tumbling consists of tumbling and resting sessions. This stop-and-go process is typically continued for a total period of 10–16 h, mostly overnight. The disadvantage of interval tumbling is that the tumbler is in use for such a long time on the same batch of meat. Interval tumbling is based on a predetermined total number of tumbling revolutions and a period of time allocated for the entire tumbling process. For example, if a total of 4500 tumbling revolutions are required over a period of 14 h (840 min) and the speed of the tumbler is 7 rev/min, then the meat has to be tumbled for about 643 min (4500/7). This leaves around 200 min for resting periods (840–643) within the 14 h. Therefore, the tumbling programme could be 45 min of tumbling and 15 min rest repeated 14 times, which would result in 630 min of tumbling, very close to the predetermined 643 min. The parameters can be adjusted to allow for different periods of time, which would result in adjustments to the speed of tumbling (revolutions per minute) to compensate and ensure that the correct number of tumbling revolutions is completed. The temperature of the meat during tumbling should not exceed 4 °C, with 0–2 °C being the optimum. Practical experience shows that interval tumbling produces a slightly higher cooking yield than split or continuous tumbling does. The periods of rest permit the protein to swell very effectively, increasing the number of muscle fibre cells that are burst by the tumbling process. Large amounts of protein are activated by the repeated cycle of swelling and tumbling. If extra brine has to be added directly to the tumbler due to underinjection, the first tumbling period must be at least 1–1.5 h so that the meat absorbs all the brine before the first resting period.

Temperature is critical for all methods of tumbling, and the period of time between the completion of the tumbling process and subsequent thermal treatment must be kept to an absolute minimum. It is important that bacteria are not allowed to grow, and semitreated products (including tumbled pieces of meat filled into the respective casing, netting or mould or hung or placed on horizontal racks) should not be exposed to warm temperatures for a prolonged period of time. Unfortunately, such raw products are often placed on smoke trolleys and left in the smoking and cooking area for a significant period of time before finally being heat treated. If the filled or formed products cannot be thermally treated immediately, they should be stored under chilled conditions.

After tumbling, the meat is soft and elastic in texture and therefore easy to fill, form or to handle in any other way. A thick layer of activated protein is present on the surface of each piece of meat, which is vital for slice coherency and cooking yield.

Practical experience shows that, if injected meat is tumbled on a Friday and left over the weekend, the cooking yield is slightly lower than meat that

has gone through the processing steps during the week without a break. Some additives, especially phosphates, lose their functionality over time and some degree of protein activation and WHC will be lost over a weekend. The phosphates start to be degraded to monophosphates by the enzyme phosphatase and, because monophosphates do not work on protein, the cooking yield is lowered. The effectiveness of other additives, such as carrageenan, soy protein and starch is generally not affected because they do not degrade. Meat injected on a Friday afternoon should be tumbled continuously for around 2 h to ensure even distribution of the brine and the creation of a thin layer of protein around all the pieces of meat. There should be no freely floating brine in the tumbler. This prevents brine from leaking out of the meat over the weekend. If the meat is not tumbled sufficiently, or not at all, there will be a large volume of brine left in the tumbler and all that brine will have to be absorbed first before being properly immobilized in the muscle tissue. The tumbling process typically starts again on Sunday afternoon, or evening, and further processing takes place on Monday morning, once tumbling is completed.

If several hours pass between the end of the tumbling process and further treatment, the layer of activated protein on the surface of the meat becomes thinner, which will lower slice coherency in the finished product. Hence it is important that the tumbling process should be completed just before filling or moulding takes place; otherwise the meat has to be tumbled again continuously for around 0.5–1 h under full vacuum before further processing takes place.

#### *Tumbling in a vacuum*

Applying a strong vacuum (–0.8 to –0.95 bar or more) during tumbling is of great benefit to the finished product. There are widespread opinions about the intensity, or strength, of vacuum that should be applied during tumbling. A high vacuum supports the swelling of the protein structure as well as the formation of the curing colour. If the vacuum is too low, however, foam formation during tumbling is increased. The presence of a strong vacuum is recommended during the entire tumbling programme, even during resting periods.

The curing colour develops more quickly in the absence of oxygen ( $O_2$ ), and therefore tumbling under a vacuum results in a stronger curing colour in the finished product. Removing  $O_2$  means that the NO, obtained from nitrite, binds more quickly and effectively to the sixth bonding point on the myoglobin (see Chapter 7, Section 7.3).

The creation of a vacuum inside the tumbler reduces the pressure applied to the meat. Atmospheric pressure, at sea level on the surface of the Earth, is 1013 mbar. Removing this pressure by applying a vacuum allows the fibrous proteins to swell much faster and more effectively. This leads to more activated (liquefied) protein and hence increases cooking yield, slice coherency and the firmness of the final product.

Additional benefits of tumbling under a vacuum include the anaerobic conditions, which dramatically slow the growth of aerobic spoilage bacteria such as *Pseudomonas* spp. Vacuum conditions also help to keep the temperature low for longer because heat conductivity is slower under vacuum than in air. The removal of air from the tumbler also reduces the formation of foam, which is obtained when air is introduced into the liquefied (activated) protein–water solution. Foam affects slice coherency in the finished product because air bubbles trapped in the foam expand during thermal treatment, causing breakage between individual pieces of meat. Foam also affects appearance because the layers of foam are lighter in colour than the meat, giving the finished product a patchy appearance. Foam is difficult to remove. The most effective, but very-labour-intensive, remedy is to wash the foam off the tumbled meat with cold water and then to tumble the meat again for around 1–2 h under full vacuum. This process reduces the level of foam but does not eliminate it because it is impossible to remove all the trapped air. Where permitted, a liquid anti-foaming agent can be added into the tumbler and the tumbled mass is just gently mixed for a short while without vacuum thus reducing the amount of foam seen on the tumbled pieces of meat.

#### **8.4.5 Filling**

Tumbled meat has a thick layer of protein on its surface, and so care must be taken that it does not come into direct contact with water because water would dilute the surface protein and seriously affect slice coherency. This is a problem for ham production, because the surfaces of the working tables where the tumbled meat is often handled before being placed into ham moulds are typically covered with water. To avoid this, the tumbled meat should be placed straight into the moulds when it is removed from the tumbler.

Moulds are prepared by lining them with a layer of plastic or similar material. The plastic must be large enough that it can be folded over the entire meat mass during thermal treatment. If the mould is not lined, some of the meat will stick to the mould during cooking, making it almost impossible to remove the cooked product from the mould, and also leading to cross-contamination between the mould and the tumbled meat. In addition, the lining helps to reduce cooking loss during thermal treatment. Moulds must be kept clean and must be free of rust or any other foreign material.

Properly tumbled meat is elastic and soft; so it is easy to prevent the occurrence of air pockets between the individual pieces of meat when the meat is placed in the mould. Usually, a layer of pork fat around 5–10 mm thick with the skin on is placed at the bottom of the mould with the skin down so that the meat comes into contact with the fat. The fat provides a nice contrast to lean meat, giving the ham a more ‘natural’ appearance and, in addition, the fat is sold at the same per-kilogram price as the ham. The fat is added to the tumbler for the last hour or so of tumbling, which introduces

some nitrite and activated protein and therefore supports binding between pieces of meat and the fat during cooking. Sometimes, the prepared layers of fat are placed in brine containing around 2–3% salt and around 200 ppm of nitrite for 12–24 h before being added to the final stage of tumbling. The bacteria count of the fat and skin must be low; otherwise the shelf life of the cooked product will be seriously reduced.

The tumbled pieces of meat are put in the mould with the muscle fibres running along the shape, or direction, of the mould so that when the cooked ham is cut or sliced, it is cut against the direction of the fibres. This results in a softer bite and a more attractive surface appearance.

Filled moulds (without the lid on) are commonly placed in a vacuum machine to remove any air that might be trapped between the pieces of meat. The meat is then covered with the extra plastic liner and the lid is firmly attached. The lid must be placed horizontally on the mould and the same pressure applied to both sides of the lid and the contents to close it. Filled moulds are occasionally left to stand for around 6–8 h in temperatures around 0–2 °C, which helps to eliminate any remaining small air pockets. The problem with this treatment is the additional handling and space required.

Whole-muscle hams can be made by vacuum packing tumbled meat (–0.99 bar or a 99% vacuum) before it is placed in the mould, which eliminates cooking loss. The sealed vacuum bag is placed in the mould and the lid firmly attached. These ham products, properly thermally treated and sold as a whole piece (non-sliced), have an extremely long shelf life because no recontamination occurs after cooking. Trials showed that these hams had a very low bacteria count even after prolonged storage at 0–2 °C, up to at least 7 months. The vacuum bag also removes another processing step because it serves as the packaging.

Tumbled meat for re-formed whole-muscle products is filled into fibrous or other permeable casings. The filling pipe should have a large diameter to avoid squeezing the meat as it passes through the pipe. The filling speed should be slow enough to allow the meat to fill the casing properly. Tumbled meat for hams, or individual large pieces of meat, may be filled into a collagen foil or netting, although netting is not normally applied directly to the meat as it sticks to the product after thermal treatment is completed and is very difficult to remove. Normally, a collagen foil is placed around the meat first and the netting placed on top of the foil. Netted products are often placed in a vacuum to remove any residual air trapped in the product. There are casings available that combine collagen and netting. More commonly, tumbled meat is filled into waterproof casings, which eliminate any degree of cooking loss during thermal treatment. Whichever casing (foil or netting) is used, the tumbled meat must be packed tightly and without air pockets. Air pockets reduce the firmness of the finished product and also contain gel, which is visible in the finished product. Air pockets also affect the colour, because the presence of O<sub>2</sub> alters the colour from curing red to brown–green, as slice coherency is also negatively affected by air pockets.

Fibrous and waterproof casings generally have to be soaked for around 30 min in lukewarm water before being filled (see Chapter 35, Sections 35.4 and 35.5). Sophisticated filling machines can fill even large-diameter fibrous casings without tearing the individual muscles and the casing processed is commonly handled in the shirred form. Very-large-diameter fibrous casings are filled by hand and it is necessary to use a compressing device afterwards to make sure that the product is correctly filled before being clipped. Casing suppliers will provide any particular information regarding the use of each type of casing. There are fibrous casings available with a layer of smoke on the inside, which can be used to eliminate the processing step of smoking. Casings with a layer of smoke at the inside are filled using the largest filling pipe possible to avoid back flow, which might otherwise cause uneven colouring after cooking.

Non-permeable or waterproof casings have similar properties and constraints, with the correct handling and treatment methods depending on the type of casing used. Filling into printed waterproof casing, which has the name of the product and all other required information, is becoming more and more popular, because the casing serves as packaging and no additional packaging is required. The shelf life of a product filled and thermally treated in a waterproof casing is excellent because there is no recontamination after being cooked.

Large hams filled into fibrous or waterproof casings, large boneless hams and other pieces of injected meat filled into netting, are placed in additional netting if they are to be smoked and/or cooked by hanging on a trolley or other device. This extra netting carries the actual weight of the product itself. If extra netting is not used for heavy products, the final product will be pear shaped because of the effect of gravity on the casing and its contents. The disadvantages of pear-shaped products include uneven binding between pieces of muscles, and uneven diameter when sliced. This is a common problem for hams filled into long log casings, which can be up to 1.5 m long. Log casings are used for more efficient slicing and can weigh more than 15 kg. In worst-case scenarios, an uneven-diameter product will not fit into the specified packaging after slicing. An alternative to the use of extra netting for logs is to place them horizontally on racks during the smoking and cooking process, which prevents them from becoming pear shaped. Ham products made from an entire boneless pork leg folded together after tumbling and netted are particularly susceptible to the effects of gravity on binding, slicing and appearance. This type of product either should be placed horizontally on racks after being netted or should be hung by an additional net to carry the weight so that the correct shape is maintained. If racked horizontally, another rack is placed on top of the product and the two racks are fixed tightly together to apply additional pressure to the ham during heat treatment and to ensure evenly sized products. Re-formed whole-muscle ham in large fibrous casings (with a diameter of 140 mm or larger) can be put into grid moulds, which can be tightened up on both sides in order to apply sufficient and even

pressure to the product during heat treatment. Products in grid moulds can be hung for heat treatment because the mould carries the weight. Ham in a grid mould ends up an oval shape. Casings that are filled to around 75% of capacity and then placed on racks result in a D-shaped product.

Casings are clipped when filled, and care must be taken to ensure that the clips are positioned correctly. If the casing is clipped too loosely, it will not withstand the expansion of the meat during heat treatment and hung products will fall during cooking or the contents will be pushed out and fall on to other products placed below them. Moving the clip horizontally lowers the tension on the contents, resulting in poor slice coherency and a non-uniform shape. If the clip is attached too tightly around the casing, it can cut the casing and the casing will split during heat treatment, so the product will fall out. Older models of clipping machines form each clip individually out of an endless metal cord. The position where the cord is cut must be set correctly to prevent the clip from having sharp edges. In general, a clip has to be chosen, or formed, in such a way that the bundle of casing is well covered and tightly closed.

Quite a few cooked ham products, predominantly those consisting of a single muscle, are not put into a casing. Individual pieces of tumbled meat are placed horizontally on smoking racks, or just hung, and then further heat treated. Sometimes the meat is covered in spices or herbs after tumbling and then hung on smoking sticks. The activated layer of surface protein acts as the glue, holding the spices or herbs applied.

The period of time between filling and heat treatment of a ham product should be kept to a minimum to prevent the growth of bacteria and the associated risks to the final product. Bacterial growth can affect taste by fermenting the sugars present into acid and can reduce cooking yield by lowering the pH, which is also associated with less WBC as the product approaches the IEP. If there is a long gap between filling and heat treatment, then the heat treatment must be more severe to kill the bacteria and hence to achieve the desired shelf life. The more severe the heat treatment, the greater is the loss in weight, unless the product is filled in a waterproof casing, which in turn increases the risk of water separation.

#### **8.4.6 Smoking**

Ham products, re-formed or as single pieces, are commonly smoked to improve colour, taste and shelf life (see Chapter 6, Section 6.11 and 6.12). Shelf life is improved because smoke contains acids in the form of phenols, which lower the pH on the surface of the product and thus have an antimicrobial effect. Around 25 different phenols have been isolated so far from smoke. Phenols also act as an antioxidant.

The simple organic acids (one to ten carbon atoms) found in smoke occur in the gaseous and particle phases. Acids containing one to five carbon atoms, such as acetic, propionic, butyric and formic acid, are primarily found

in the gaseous phase, while those containing five to ten carbon atoms, such as caproic acid, heptylic acid and valeric acid, are found in the particle phase. Friction smoke contains lower levels of phenols than smoke originating from sawdust or woodchips, but higher levels of acids and carbonyls, thus leading to differences in colour and taste. Smoke from hardwood such as hickory gives a nicer flavour than smoke from softwood such as pine.

Meat products to be smoked must first be dried so that the surface can absorb the smoke, unless a very-dark-coloured, or pit-smoked, product is wanted. Drying should not begin until a minimum of around 12–14 h after injection to allow sufficient time for a strong curing colour to develop, especially as injected meat is kept in a cold environment during all earlier processing steps. Drying before smoking also contributes to the development and stabilization of curing colour, as drying generally takes place at around 60–70 °C and at RH levels of 30–40%. The temperature and humidity greatly speed up colour development, and the drying process lasts between 30 min and 2 h, depending on the level to which the smoking chamber is filled, and the diameter or size of the products. Drying is carried out in such a way that the surface becomes dry but is not overdried as some moisture is still required on the surface of the product for smoke particulates to stick to the surface.

Once the surface is dried properly, smoking is the next step. For liquid smoke, the correct amount of smoke has to be injected into the chamber and short periods of drying allowed after each application of smoke to fix the colour on the surface. Manufacturers of liquid smoke specify the products most suitable for smoking in this way. Liquid smoke obtained from both hardwood and softwood results in an acceptable flavour. Natural smoke is applied at 65–75 °C and 50–70% RH until the desired smoke colour is obtained. To fix and strengthen the natural smoke colour even further, a short period of drying is introduced around halfway through the smoking cycle.

Re-formed ham products are frequently dried and smoked, and then sliced after heat treatment using high-speed slicing machines. The smoking forms a thin hard ring around the product, which makes it easier to slice the product in a high-speed machine. Products made out of a single individual muscle and covered with spices or herbs also have to be dried first at 65–75 °C and low humidity so that the layer of activated protein denatures and fixes the applied coating. Coated products are commonly slightly smoked afterwards as well.

Generally, drying continues until a dry surface that can absorb smoke easily is obtained. Overdrying results in poor smoke absorption and hence pale-coloured products. Heavily smoked and dark-coloured ham products are obtained by keeping the drying process very short or by not drying the meat at all. A moist surface absorbs smoke particles easily and smoking at around 65–75 °C for a long period of time results in a dark or almost black product (see Chapter 6, Section 6.11). The meat is then dried at around 75 °C and very low RH to fix the colour.

Generally speaking, the amount of smoke taken up by the surface of the product depends on a number of parameters, including the RH in the

smokehouse during smoking, the density of smoke inside the chamber, the air velocity during smoking and the surface of the product being smoked. High air velocity promotes the uptake of smoke but at the same time lowers the density of the smoke. High RH during smoking also enhances the uptake of smoke, as does a moist surface.

#### 8.4.7 Cooking with moisture (steam or water)

The action of heat on the meat coagulates proteins and improves sliceability and slice coherency. Cooking is the term commonly used for meat products that are heat treated, but pasteurizing is the more precise description. Cooking normally refers to the boiling point of water, which is 100 °C at sea level, but the majority of meat products are not heated to such high temperatures (retorted products are the exception). Pasteurizing takes place at a temperature range between 72 and 85 °C and, in meat products, this process denatures proteins, stabilizes the curing colour, intensifies the flavour, improves the texture and destroys pathogens. Sterilizing (or retorting) takes place between 110 and 121 °C. Pasteurized products can be stored for a prolonged period of time under refrigeration temperatures below 4 °C, because all vegetative pathogens are destroyed, but spores may survive heat treatment.

Frequently, an integrated  $F$ -value calculator is combined with the cooking process and cooking is stopped once the desired  $F_{70}$  value (see Chapter 40) is obtained. Generally,  $F_{70}$  values of around 40–60 min are required in whole-muscle cooked hams.  $F_{70}$  values of around 45–50 min are obtained when a certain core temperature is reached. During the decline in core temperature to 55 °C, an additional 10 min are obtained, resulting in a total  $F_{70}$  value of around 60 min. Those  $F_{70}$  values are common when aiming for core temperatures of around 66–68 °C. Higher core temperatures of around 70 °C, especially in large products, frequently result in  $F_{70}$  values between 80 and 100 min, which is beneficial for the shelf life of the product. The impact on shelf life and the destruction of vegetative pathogens can be based on reaching a desired core temperature or on the  $F_{70}$  value attained.

Calculating the destruction of pathogens by applying predetermined  $F_{70}$  values provides a more precise method for quantifying improvements in shelf life than aiming for a certain core temperature. A desired core temperature, such as 70 °C, can be achieved quickly in a small-diameter product by applying a fairly high cooking temperature, say 80 °C. However, only a few pathogens might be destroyed because of the short heating time.

Dried, or dried and smoked, products, are predominantly heat treated in steam or water. Using a water bath transfers heat more efficiently to the product than steam because the moisture level on the surface of the product is 100% in a water bath whereas steam is never fully saturated and therefore cannot achieve this level. Cooking at constant temperature, step cooking or  $\Delta T$  cooking are three common methods of moist thermal treatment, and cooking normally takes place at 74–80 °C until a core temperature of 69–

72 °C is obtained. Cooking and core temperature specifications are highly debated among experts because a compromise between product safety, economic factors (e.g. cooking loss), stabilization of curing colour and functionality of additives has to be reached. Heating a product to a core temperature of 72 °C is much safer from a microbiological point of view than heating to a core temperature of 68 °C, but there is a substantial difference between the cooking yields at these temperatures, particularly for large-diameter products. As a rule of thumb, larger-diameter or large products made of a single muscle (e.g. leg ham on the bone) are cooked to a slightly lower core temperature than small-diameter or small products. This can be explained by considering the  $F_{70}$  value, because the fundamentals behind the killing of bacteria are based on the combination of temperature applied and length of time, which are the basics for calculating the  $F_{70}$  value as well. High temperatures are present for longer inside large products, even if the final core temperature is slightly lower. Thus the killing effect for a large product is similar to the effect of applying slightly higher core temperatures for a shorter period of time in smaller products.

In certain parts of the world it is common to cook a ham to a core temperature of 66–68 °C and to hold the temperature at this point for a certain period of time, for instance around 30 min. However, proteins such as myoglobin are not fully denatured by temperatures below 70 °C and there can be problems with colour stability using this method, as insufficiently denatured nitrosomyoglobin turns into metmyoglobin over time, contributing to early fading of the red curing colour into brown and grey. Another drawback is that additives such as carrageenan and most types of starch require a temperature of at least 69 °C to become fully functional and to form the desired gel on cooling. Ham products also typically contain sugars, and again a core temperature of 69–70 °C is necessary to kill the bacteria that would otherwise ferment the sugar into CO<sub>2</sub> and cause holes in the finished product. Fermenting sugars in the final product can also cause the packaging to balloon, and the formation of slime, or milky purge.

Re-formed ham products filled into waterproof casings and not dried or smoked are steamed or cooked in water at temperatures between 74 and 80 °C until the core reaches 69 and 72 °C. Non-smoked products are sometimes given a smoked flavour by adding flavouring to the injection brine. Re-formed whole-muscle ham products, filled in waterproof casings, are produced in such a way that there is no cooking loss during thermal treatment and no separation of water occurs during cooking either. The cooking yield of whole-muscle and cooking-loss-free hams varies generally between 130% and 200%.

Smoked products, as described above, are dried before being smoked and cooked, and the drying period lasts for around one third of the total cooking time. Once drying and smoking is completed, steam at 74–80 °C is applied until the desired core temperature or  $F_{70}$  value is reached. In large-scale operations, the processing steps of drying, smoking and cooking generally take

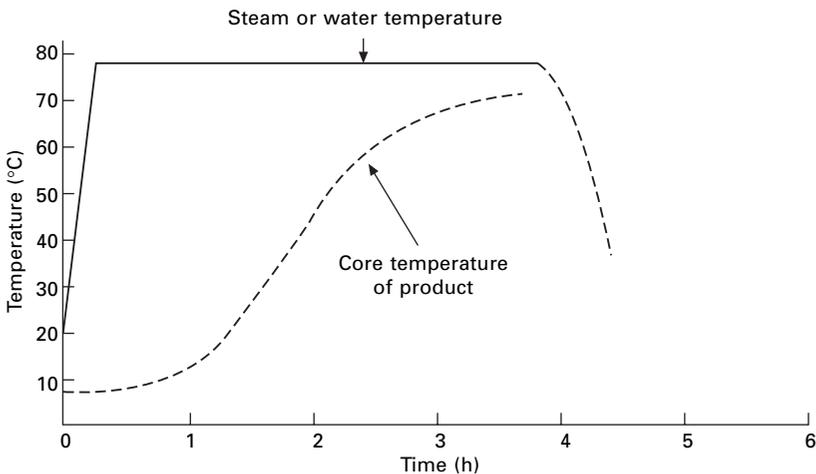
place with the product being hung or placed on racks. Steam is the preferred cooking method because cooking in a water bath requires additional handling.

Ham products coated in herbs or spices are commonly cooked at constant temperature in steam, but only after the drying and optional smoking are completed. Such products cannot be cooked in a water bath as the outside coating would wash off.

Large individual pieces of meat, such as beef silverside, are either hung and cooked with steam or put in a plastic bag and placed horizontally on racks. The bagged product can be cooked in steam or in a water bath. Meat that is bagged is submerged in cold water before the bag is closed to remove any air present between the piece of meat and the bag, taking care that no water enters the bag itself. The pressure of the water on the bag forces the air out and the bag is then tied off. Removing air from the bag reduces cooking loss and shortens the cooking process, as air is a poor conductor of heat.

#### *Cooking at constant temperature*

Cooking at constant water or steam temperature (Fig. 8.5) is the most common method of thermal treatment for re-formed whole-muscle ham products and large individual pieces of meat. With this method, the product is exposed to a constant steam or hot water temperature right from the beginning of the cooking process. The temperature used is generally between 74 and 80 °C, as temperatures higher than 80 °C result in excessive cooking losses. Cooking with this method is complete, once the desired core temperature (commonly between 69 and 72 °C) or the desired  $F_{70}$  value is reached. Thus the steam or water for constant-temperature cooking is around 6–10 °C above the desired final core temperature. If the difference in temperature between cooking and core temperature is too small, e.g. 2–4 °C, the cooking process is significantly prolonged, which results in economic loss. The core temperature



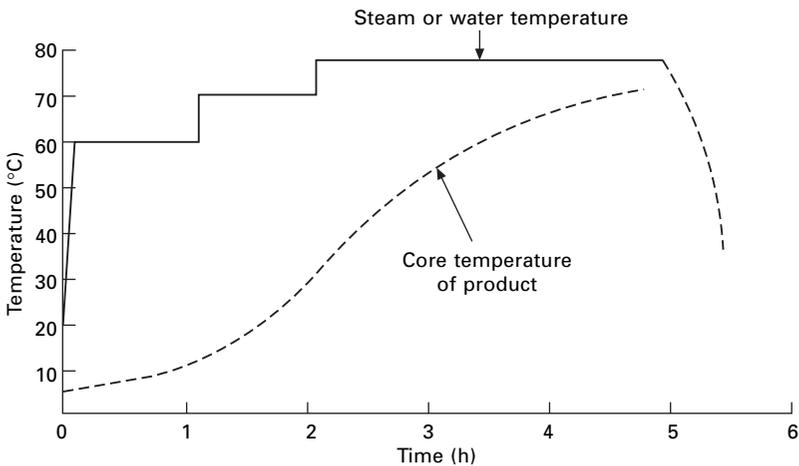
**Fig. 8.5** Cooking at a constant temperature.

should pass through the range from 7 to 55 °C as quickly as possible because that temperature range does not kill bacteria or affect curing colour. If the product stays too long in the 7–55 °C range, bacteria will grow rapidly between 30 and 50 °C, the ideal temperature range for bacterial growth. The advantage of cooking at constant temperature is that the desired core temperature, or  $F_{70}$  value, is reached in a shorter period of time than other methods of cooking. However, the disadvantage is that there is slightly a higher cooking loss for products being cooked without any casing or products filled into a fibrous casing, netting, mould or collagen foil than for other cooking methods. Cooking at constant temperature is the standard cooking method for ham products in waterproof casings, where there is no cooking loss and the desired core temperature is reached in the fastest possible time. This cooking method is also commonly applied for hams in fibrous casings and moulds, and netted products.

### *Step cooking*

Step cooking, as the name suggests, involves cooking the meat at different temperatures in a series of steps (Fig. 8.6). The product is exposed to a steam or water temperature of around 60 °C for a certain period of time (usually around 1 h) in the first stage. Meat proteins denature strongly at temperatures above 60–65 °C and, if higher temperatures are applied at the beginning of the cooking process, then the yield will probably be slightly reduced. Large products in particular should be treated at 60–65 °C for at least 1 h before increasing the temperature. The temperature is then increased to 70 °C for a specified time (another hour or so) and finally up to 74–80 °C until the desired core temperature, or  $F_{70}$  value, is reached.

Step cooking is predominantly used for larger products, as the gradual increase in temperature at the beginning could bring smaller products straight to the desired final core temperature. The length of each step before the final



**Fig. 8.6** Step cooking.

cooking temperature is reached depends on the diameter of the casing used or the size of the individual piece of meat.

Although step cooking is not as fast as cooking at a constant temperature, the cooking loss is lower. Cooking large ham products in waterproof casings with this method reduces the risk of water separation as the protein has more time effectively to immobilize the added water. The gradual increase in temperature over time contributes positively to a stronger curing colour as well.

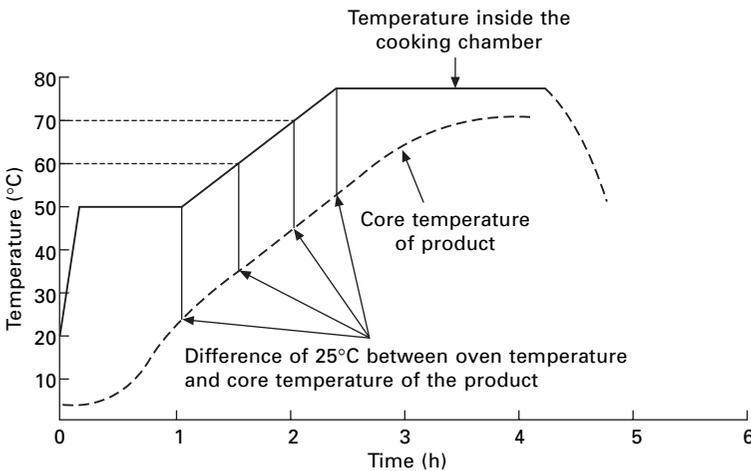
The disadvantage of step cooking is the prolonged cooking time required compared with cooking at a constant temperature. The meat must not be kept at 60–70 °C for prolonged periods of time because the core temperature will remain in the range 7–55 °C for long enough to create a significant risk of bacterial growth. Step cooking is most commonly carried out using steam.

### *$\Delta T$ cooking*

Large-scale ham manufacturers use  $\Delta T$  cooking (Fig. 8.7), which can be carried out using steam or a water bath but is typically carried out in steam. Treatment of the product starts at between 60 and 65 °C. A temperature probe is placed inside the product and a difference between the temperature in the cooking chamber and the temperature inside the product, namely  $\Delta T$ , is predetermined.  $\Delta T$  should be at least 25 °C, and  $\Delta T = 30$  °C is more commonly applied.

For  $\Delta T = 25$  °C, the temperature in the cooking chamber remains constant at, for example, 60 °C during the initial stage of the cooking process, until the temperature inside the product rises to 35 °C. At this point the difference between the temperature of the cooking chamber (or water bath) and the temperature of the core of the product is the required 25 °C.

Once this point is reached, the temperature inside the cooking chamber (or the water temperature) starts to rise and the core temperature inside the



**Fig. 8.7**  $\Delta T$  cooking.

product rises at the same rate. The predetermined  $\Delta T$ , i.e. the difference between the temperature of the cooking chamber and the temperature of the core of the product, of 25 °C is always maintained. Once the temperature inside the cooking chamber, or water bath, reaches a predetermined maximum point, e.g. 78 °C, the temperature is kept constant. As a result, the difference between the temperature in the chamber and the core temperature of the product becomes less than 25 °C, and the core temperature keeps on rising until a preset core temperature, commonly between 69 and 72 °C, or  $F_{70}$  value is obtained.

The advantage of  $\Delta T$  cooking is that it achieves the highest cooking yield of all three methods of cooking. The cooking yield for  $\Delta T$  cooking on larger products is around 2–4% higher than the other methods. The disadvantage is the lengthy overall cooking time. Large-scale producers can use  $\Delta T$  cooking economically because the smoking and cooking can take place overnight using cheaper night-time electricity, and the combination of lower electricity costs and 2–4% higher cooking yield makes this method cost effective.

#### **8.4.8 Cooking with dry heat**

Cooking with dry heat is equivalent to baking and is typically carried out at around 76–80 °C. Dry-heat cooking is continued until the desired core temperature is reached, usually between 69 and 72 °C. Dry heat results in a distinctive flavour and strong colour in the finished product. The Maillard reaction occurs and various flavour components develop more strongly under the impact of dry heat than in the moist heat of steam or water. Products where a strong smoke flavour and a strong smoke colour are desired can be hot smoked at 76–80 °C and in an RH of 50–70% and here both processes, i.e. smoking and cooking, occur simultaneously until the desired core temperature is reached.

The dry-heat method lowers cooking yield, because dry heat draws more moisture out of the product and heat transfer into the product takes place at a slower rate. Products coated with herbs or spices can be cooked with dry heat after smoking, or hot smoked, and this helps the herbs or spices to adhere to the surface.

Cooking loss must be balanced against the impact on shelf life; thus both final core temperature and  $F_{70}$  value must be taken into account when comparing different cooking methods. It is possible to reach core temperature quickly, especially in small-diameter products, and this keeps cooking loss relatively low. However, quick cooking results in a low  $F_{70}$  value and so shelf life might be poor. The basic principle behind cooking meat products is that the application of heat, whether wet (steam or hot-water bath) or dry (baking and roasting) transforms proteins from their solubilized and native state into an irreversible denatured state. The same transformation can happen under a high pressure, in the region of 600–2000 bar. High pressure denatures proteins

and meat exposed to a high pressure would therefore technically be cooked. High-pressure cooking is advantageous because it takes only a few minutes to build up the necessary pressure, compared with hours of traditional cooking with moist or dry heat. Because the pressure treatment is fast, the core temperature of the product only rises to around 25–30 °C and hence it is easy and quick to chill the meat to below 5 °C afterwards. Not only does this save large amounts of energy (and cost), but it also benefits shelf life because bacteria have little chance to grow. Cooking food by the application of high pressure is currently much more common in other industries, such as the beverage industry, and Japan is in the forefront of this particular method. The technology for using high-pressure cooking in the large-scale manufacture of meat products is under development. Microwaves are not used to cook meat products because the heat distribution is uneven and the microwaves can only penetrate the outer layers of the product.

Cooking products in a direct-fired gas oven can cause pinking of non-cured products. Nitrogen dioxide (NO<sub>2</sub>) is produced, which is soluble in water and therefore penetrates into the outer layers of non-cured products, causing the formation of pink colour.

#### **8.4.9 Cooling**

Some waterproof casings must be showered after cooking to prevent wrinkles from forming as the meat cools, although there are quite a few waterproof casings on the market today that stay wrinkle free without showering. Meat products in fibrous casings should be showered with cold water for around 15–30 min in order to cool the product and to keep the casing moist so that it shrinks with the product during cooling. Showering is normally carried out at intervals rather than continuously, which has two major advantages. Firstly, continuous showering of a hot product traps the heat in the product because of the permanent layer of water present on the surface. The thermal conductivity of water itself is very poor and by showering continuously, the cooling effect is quite limited because the layer of water on the outside of the hot product creates a barrier, acting as an insulator. During interval showering, the hot product is showered for several minutes and then left to stand for several minutes. During the standing period, internal heat reaches the surface and is taken off by the air. The showering is repeated to prevent the casing from splitting and wrinkling, and the whole cycle is repeated several times. Practical experience shows that showering in intervals has a greater cooling effect than continuous showering and the overall cooling time is therefore reduced.

The second advantage of interval showering is that by reducing the actual showering time by half, large amounts of water are saved. This can result in significant cost savings for companies that have to pay, firstly, for the water consumed and, secondly, for the amount of water running into the sewage system afterwards. Large companies, where showers or sprinklers are in

operation almost continuously, recycle the showering water as well, because water is a substantial cost factor for large meat-processing companies.

When showering is completed, the products are commonly placed in a blast chiller to cool them quickly to below 10 °C. This is critical because most vegetative pathogens are killed during the cooking process, but spores from bacteria such as *Bacillus* spp. and *Clostridium* spp. can survive and then germinate and grow at temperatures above 10 °C. If a product is cooled too slowly, the core temperature remains between 55 and 10 °C for a long time, ideal temperatures for bacterial growth and spore germination. Gram-positive bacteria are a serious risk for food poisoning and shorten the shelf life of the product significantly. Some bacteria, such as *Salmonella* spp., can grow at temperatures as low as 5–7 °C; so the final temperature of 0–3 °C should be reached quickly. Several countries have guidelines in place as to how quickly cooked ham or other whole-muscle products must reach a certain core temperature.

Re-formed ham products cooked in moulds are commonly showered with cold water, or placed in a bath of cold water, for around 15–30 min before being placed in a blast chiller or chiller at temperature around 0 °C. No additional pressure should be placed on the lid of the mould once the ham is cooked, because strong pressure after cooking would have a highly negative impact on the slice coherency of the finished product.

When hams cooked in moulds are put into cold water, the core temperature rises by 1–2 °C because heat in the outer layers of the ham moves away from the area of cold at the surface towards the core of the product. Moulded hams and re-formed ham products should not be cooled in a freezer. Different muscles present in a re-formed ham product shrink at different speeds during cooling and, if cooled too fast, the layers of protein between the individual muscles can break and slice coherency is lost. However, placing still warm ham in a freezer is common bad practice if moulds are needed for reuse. Chilled hams can only be removed from the mould once completely cooled. If hams are removed when they are still warm, the individual muscles extend differently and coherency obtained between the individual muscles during cooking can be lost and the sliced product will fall apart as a result.

Ham products that require a smoke colour are removed from the mould when fully chilled, the plastic liners are removed, and the products are placed on smoking racks. They are then dried at around 60–70 °C for 15–30 min, and slight smoking is then applied at about 70 °C for 20–30 min. This results in a golden-brown colour and a light smoke flavour in the final product. The smoke also increases shelf life owing to the effect of smoke and heat on the surface of the product. Products coated with herbs or spices are not showered or placed in a bath of cold water after heat treatment because this would wash off some or most of the coating. These products go straight from cooking into the chiller. Products filled in waterproof casings which do not need any further handling (for instance slicing or packaging) should be stored at between –1 and 2 °C once they are fully cooled.

#### **8.4.10 Slicing and shaving**

Slicing and shaving have become much more efficient in the last few years and fully automatic slicing lines produce sliced and packed products today at impressive speeds. However, slicing and shaving carry a high risk of contamination. The key to effective and cost-efficient slicing lies in starting with a standardized product (shape and length) so that the slicer is used most effectively and offcuts and lower-quality products are minimized. Logs are produced to fit the feeding device of the slicer exactly so that slicing proceeds uninterrupted for as long as possible. Modern slicing equipment communicates electronically with the cutting section so that a specified weight per packaging unit is obtained. Overpacking, or having to add another slice to the pack to meet the desired weight, is very costly and accurate slicing reduces the amount of giveaway significantly. The difference between slicing and shaving is basically the thickness of the slice itself. A shaved product is significantly thinner than a sliced product and is generally translucent.

Enormous efforts are made, and indeed required, in order to maintain an exceptionally high standard of hygiene within slicing areas. High levels of personal hygiene are essential for high standards of factory hygiene. Staff working in areas where raw meat is handled, or in the smoking and cooking section, must never enter the slicing area. Usually, this strict separation is achieved by dividing staff and processing sections into pre- and post-cook areas, and no member of staff is allowed to cross over from one area to the other. Modern slicing rooms also often use negative or positive air pressure to prevent contamination of the air in the slicing room. Either filtered air is sucked into the slicing room or air is forced out from the room. This is especially important if rooms such as boning or salami fermentation are next to the slicing room, although factories should not be constructed with this configuration in the first place. The principle of strict prevention of contamination applies to all slicing rooms, regardless of which type of product is to be sliced.

Good binding between the individual pieces of meat and a uniform casing diameter are prerequisites for obtaining a good slicing yield and slices of the same size. Slicing yield commonly refers to the percentage of sliced and packed products obtained from a certain weight of product before slicing. The optimum temperature for the product to be sliced or shaved is around  $-1\text{ }^{\circ}\text{C}$ .

The formation of condensation on the sliced product has to be avoided as shelf life and other parameters would suffer (see Chapter 4, Section 4.12). Condensation water represents free unbound water, which is readily available to bacteria. Slicing rooms frequently have an RH of around 45–60% in order to avoid the risk of condensation forming as a result of the difference between the temperature of the well-chilled product to be sliced and the temperature present in the slicing room, if the temperature in the slicing room cannot be reduced to a level not exceeding the dew point.

#### 8.4.11 Packing under vacuum

Finished products should be packed in such a way that avoids any further loss in weight and also puts a barrier into place between the products and bacteria. Curing colour starts to fade quickly under the impact of light and oxygen because photolysis occurs; complexes containing NO are broken down by the impact of light (see Chapter 7, Section 7.3). Vacuum packing delays microbiological spoilage because spoilage caused by anaerobic bacteria takes place at a significantly slower speed than spoilage caused by aerobic bacteria such as *Pseudomonas* spp. and vacuum packing removes O<sub>2</sub>. Keeping vacuum-packed products at a low storage temperature around 0 °C is a powerful combination against bacterial growth and greatly extends shelf life. Vacuum packed products are most often spoiled through acidification by acid-forming *Lactobacillus* spp.

The degree of vacuum applied has to be very strong, and –0.99 bar should be obtained before the bag is sealed. Care must be taken that the vacuum bag is heat sealed properly and the seal must not cut the bag, which is frequently the case when heat is applied for too long during sealing.

Chilled and non-sliced products are often packed into vacuum bags and dipped into hot water (85–95 °C) for 2–3 s after being vacuum packed. This short exposure to high temperatures is known as post-pack pasteurization (PPP) and results in a significant reduction in the number of bacteria on the surface of the product, enhancing shelf life. Dipping helps prevent purge and *Lactobacillus* spp. as well as *Streptococcus* spp. which cause souring, are effectively destroyed as well. Dipping in hot water also causes the bag to shrink, which means that it becomes tightly aligned to the surface of the product and thus makes the product visually attractive. The tightness also applies some pressure on the product and helps to delay, or prevent, the formation of purge.

Shrink bags are commonly made from three layers and PPP is frequently used in products sold as a whole piece, cut into halves or sliced. PPP is more useful for sliced products that are packed in a shingle formation rather than stacked, because the inner surfaces in a stack will not be exposed to the heat. Slices packed in shingle formation have a larger surface area exposed to the heat and PPP is effective.

Chilled ham products should not be frozen because the process of freezing damages cell walls and a dry as well as tasteless product results, with poor slice coherency, once the frozen ham product is thawed.

Recontamination, or secondary contamination, is the keyword in all products to be packed regardless of whether they are packed as a whole piece, sliced or shaved, and must be avoided or kept to the absolute minimum level possible. Every single bacterium introduced on to the surface of the product during packing shortens the shelf life. Wearing gloves frequently gives a false sense of security while other basic elements of hygiene are neglected.

Vacuum packing can also be carried out in moulds formed by a thermoformer packaging machine. The product to be packed is placed into moulds formed

from a flat layer of plastic. A vacuum is applied and the top foil is attached to the bottom and seals the packaging. No pieces of the meat product, fat or any other material must be present between the layers of packaging when the foils are connected as the packaging will not seal properly.

#### **8.4.12 Packing under a modified atmosphere**

The advantages of packing products under a modified atmosphere are that the individual slices do not stick together and the product is not squeezed as it is if packed under vacuum. This method is predominantly used for shaved and sliced products. Shaved products are generally modified atmosphere packed and lie loosely in their packaging. Shaved ham cannot be vacuum packed in shingle or stack form given that the slices are too thin to arrange. The gas mixture used in modified-atmosphere packaging generally consists of N<sub>2</sub> and CO<sub>2</sub>, containing 50–70% N<sub>2</sub> and 30–50% CO<sub>2</sub>. The most common combination is 70% N<sub>2</sub> and 30% CO<sub>2</sub>. The CO<sub>2</sub> extends shelf life by acting on the surface as carbonic acid, and the N<sub>2</sub> is used as a filler gas to keep O<sub>2</sub> out. CO<sub>2</sub> also inhibits enzyme-catalysed reactions within the cells and disrupts cell membrane activity, all of which contribute to reducing bacterial growth and extending shelf life.

Care must be taken to avoid excess levels of CO<sub>2</sub> and hence carbonic acid because purge formation will be increased owing to the reduced WBC (drop in pH). N<sub>2</sub> is used because it is an inert gas and does not react with the product. The O<sub>2</sub> level in a modified atmosphere should not exceed 0.6%.

Modified atmospheres are typically created using gas bottles containing the correct mix of N<sub>2</sub> and CO<sub>2</sub>. When separate bottles of CO<sub>2</sub> and N<sub>2</sub> are connected to the packaging line, care must be taken to ensure that the correct gas mixture is introduced into the modified-atmosphere packaging. If excess N<sub>2</sub> is introduced into the packaging, and consequently insufficient CO<sub>2</sub>, the shelf life of the product is greatly reduced. On the other hand, if excess CO<sub>2</sub> is introduced, the product turns sour because CO<sub>2</sub> reacts with water from the product to form carbonic acid ( $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$ ). Elevated levels of CO<sub>2</sub> in modified-atmosphere-packed products can also cause a pseudovacuum effect due to the high solubility of CO<sub>2</sub> in water under cold temperatures, and excess levels of CO<sub>2</sub> can cause the packaging to balloon at elevated temperatures. CO<sub>2</sub> works most effectively at lower temperatures, between –1 and 2 °C, and the combination of modified-atmosphere packaging and storage at such low temperatures results in excellent shelf life.

#### **8.4.13 Storage**

Packed products should be stored between –1 and 4 °C for optimal shelf life and, to keep bacterial growth at a minimum, 4 °C is the absolute maximum temperature for storage. Each drop of 1 °C below 4 °C extends the shelf life dramatically, and a maximum temperature of 2 °C is commonly aimed for.

Products stored at  $-1\text{ }^{\circ}\text{C}$  do not freeze as salt present within the products lowers the freezing point to around  $-2\text{ }^{\circ}\text{C}$  (depending on the amount of salt present). At temperatures between  $-1$  and  $2\text{ }^{\circ}\text{C}$ , surviving spores are kept well under control and other vegetative bacteria cannot grow. Variations in storage temperature, especially above  $5\text{ }^{\circ}\text{C}$ , even if for only a few hours, should be avoided.

The most common bacteria associated with microbiological spoilage are *Micrococcus* spp., *Streptococcus* spp., *Leuconostoc* spp., *Vibrio* spp. and Enterobacteriaceae. Ham products occasionally look green, and this greening is frequently caused by *Enterococcus* spp., *Lactobacillus viridescens* or *L. fluorescens*. These bacteria are more active under aerobic conditions but also grow under anaerobic conditions. They produce hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) which attacks the haem fraction of the curing colour.  $\text{H}_2\text{O}_2$  is an extremely strong oxidizing agent and the red curing colour changes to green via an oxidation process. Greening inside the product is generally the result of insufficient heat treatment during cooking, while greening on the surface is caused by bacteria as a result of recontamination.

If heterofermentative *Lactobacillus* spp. are not destroyed during heat treatment, they can ferment sugars in the product, producing  $\text{CO}_2$  which causes the packaging to balloon. In vacuum-packed products,  $\text{CO}_2$  is produced by anaerobic or facultative anaerobic bacteria and never by aerobic bacteria owing to the absence of  $\text{O}_2$ .  $\text{CO}_2$  is a colourless, odourless and tasteless gas. Acid is commonly produced at the same time as gas in vacuum-packed products.

Milky purge is frequently seen in packed products. This is not a metabolic substance produced by bacteria but indicates the presence of the bacteria themselves. In fact, milky purge is only visible if large numbers of bacteria are present, which multiply in the presence of water. Normally, free liquid in packed products is clear but, if contamination becomes severe, the liquid turns from clear to milky. *Lactobacillus* spp. are primarily responsible for milkiness in purge. The milky purge is most often microbiologically stable as the pH is very low, but it does not appear attractive and can give the product a sour taste. Purge is frequently seen in vacuum-packed products as a result of insufficient binding within the product. The vacuum applied more or less sucks out moisture that has not been completely immobilized within the product.

The curing colour can be prevented from fading by protecting the product from light and  $\text{O}_2$ . Most retail packaging has pictures and other information on the packaging which minimizes exposure of the actual meat product to light in the display cabinet. The impact of light (photolysis), or  $\text{O}_2$ , gradually separates NO from myoglobin which causes the curing colour to fade as metmyochromogen is produced.

Figure 8.8 shows the manufacturing process of whole-muscle injected products.

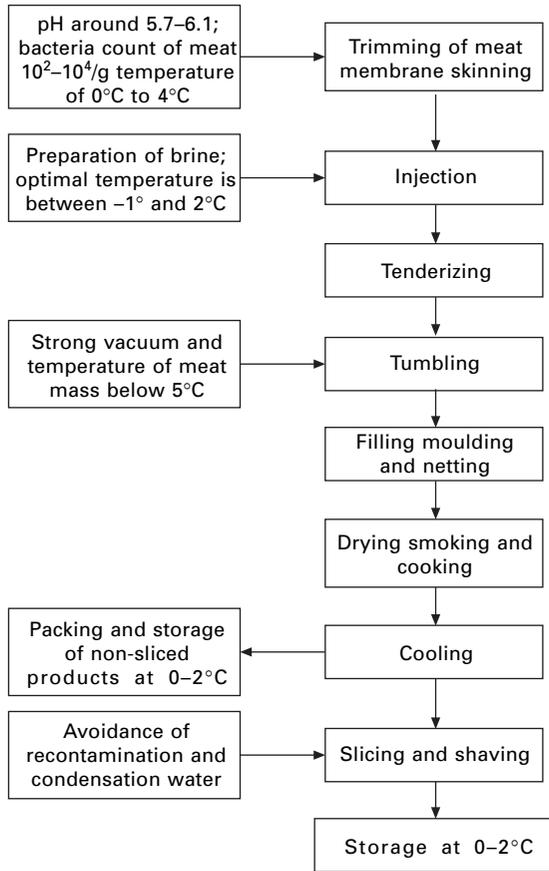


Fig. 8.8 Key steps in the manufacture of whole-muscle injected meat products.

## 8.5 Summary of critical production issues

- 1 All machines used during each processing step must be clean and free of cleaning and disinfection materials.
- 2 Selecting meat according to pH is optimal and a pH value of 5.7-6.1 is preferred.
- 3 Meat used should exhibit low bacteria count,  $10^2$ - $10^4$  per gram of product is optimal.
- 4 Membrane skinning is of great advantage and all visible fat should be removed.
- 5 The temperature of meat should be between 0 and 4 °C.
- 6 Brine must be prepared according to injection rate and desired cooking yield.
- 7 The correct amounts of additives must be added to the brine in the correct sequence.

- 8 The temperature of the finished brine should be between  $-1$  and  $2$  °C.
- 9 The level of injection into the meat must be calculated and carried out accurately.
- 10 Tenderizing after injection is very beneficial for cooking yield and slice coherency.
- 11 Sufficient tumbling under full vacuum must be carried out to activate high amounts of protein, but over-tumbling should be avoided.
- 12 Filling and moulding under vacuum avoid air pockets.
- 13 Smoking and cooking must reach the desired core temperature or  $F_{70}$  value.
- 14 Cooked products should be cooled quickly to avoid bacterial growth but not be placed in the freezer.
- 15 Factory and personal hygiene during slicing and shaving and also during packing must be extremely high to avoid condensation.
- 16 All packaging must be properly sealed in vacuum-packed products, or the correct gas mixture applied in modified-atmosphere-packet products.
- 17 Finished products should be stored at between  $-1$  and  $2$  °C and exposure to light should be kept to a minimum.

## 9

# Typical whole-muscle brine-injected products from around the world

### 9.1 Bacon (Australia)

The original Australian bacon is made from pork belly with the loin attached. This cut of meat is called middle, as it represents the midsection of a pork carcass, where the forequarter and the leg have been removed. Small amounts of bacon are produced using the loin or belly alone. After the middle has been deboned and trimmed, leaving the skin on, the resulting piece of meat is rectangular. Generally, the ribs are removed individually, which is known as string bonding. If the ribs are removed as a whole, the middle is plate bonded. Injection is between 20% and 28% and additives such as phosphates, salt, sugars, nitrite, colour enhancer and sometimes a touch of flavour are applied. Salt is present at around 24–28 g per kilogram of finished product and sugar between 5 and 15 g per kilogram of finished product. Total nitrite permitted in the finished product is 125 ppm, including nitrate being recalculated to nitrite and expressed as total nitrite. The types of additives used in bacon are currently changing because the amended food standard now permits the use of additives such as carrageenan and starch, which were not permitted prior to the amendment.

After injection, the middles are commonly soaked for 12–48 h in cover brine, which contains around 3–4% salt and around 300 ppm of nitrite per litre, in large containers. The cover brine has levels of salt and nitrite similar to, or slightly lower than, the injected meat; so osmosis does not take place. As a result, the level of salt in the injected products remains more or less unchanged during soaking. Soaking enhances the development of the curing colour, curing flavour and cooking yield because the protein fibres swell during soaking. Soaking time should not exceed 76 h, because after this length of time the functionality of phosphates begins to diminish and cooking

yield would be lowered. However, this intermediate soaking step is increasingly omitted because it requires much storage space. The soaked middles are then either hung on smoking sticks using special middles racks (hooks) or, more commonly, placed horizontally in a mould on grid racks because this method produces a higher cooking yield than hanging. Middles are placed on racks with the skin down so that it forms a natural barrier against brine running out. The moulds used are basically just the walls around the middle so that smoke and heat can penetrate the meat from underneath and from above. Another advantage of using racks is that the cooked middle is rectangular after smoking and cooking, which limits offcuts during slicing. The double gain in yield, in cooking and slicing, justifies the extra effort required for the rack method compared with hanging. Some middles are tumbled for 30–60 min at a very slow speed (2–3 rev/min) before being hung or placed on racks to improve cooking yield.

Whether hung or placed horizontally on racks, the product is subsequently dried at around 60–70 °C, smoked at 65–70 °C and finally cooked with steam at 68–75 °C until a temperature of 58–60 °C is reached in the loin, which is the thickest part of the middle. Average cooking yield on hung middles is around 104–106% whilst middles placed horizontally on racks have a cooking yield of 110–115%.

Some of the skin is removed before slicing to obtain so-called rindless bacon. Australian bacon is a product that is not fully cooked at point of sale to the end-customer and must be cooked before being eaten, usually by being fried in a pan or cooked on the barbecue grill. Bacon is mostly enjoyed with eggs for breakfast and the product itself is most commonly sold sliced and vacuum packed.

The formation of nitrosamine in bacon is frequently a point of discussion, but several parameters affect nitrosamine formation. Firstly, nitrite has to be present, which is the case for bacon. Secondly, secondary amines must also be present, but there are very few or no secondary amines present in fresh meat which is processed into bacon. Thirdly, the pH of the food must be below 5.5, which is normally not the case in bacon (and all other ham products) as WBC would be very poor at such low pH levels. Finally, a temperature above 140 °C is required, which would be the case when bacon is fried. Nitrosamine is therefore not normally a problem in bacon because no secondary amines are present and the pH is generally not below 5.5. Nitrosamine can only form in bacon if the bacon is fried or grilled to a stage where all the fat is melted out and the temperature remains above 140 °C for a prolonged period of time.

## **9.2 Bacon (New Zealand)**

Bacon in New Zealand is very different from bacon in Australia. All cuts of pork meat including shoulder and neck (forequarter) are utilized, the meat is

highly injected (around 60–90%) and all permitted additives, including phosphates, salt, soy proteins, starch, carrageenan, colours and others, are used. The amount of salt is around 22–26 g per kilogram of finished product and the level of total nitrite permitted in the finished product is 125 ppm. After injection, the meat is heavily tumbled (4000–5000 rev) and typically filled into large-diameter fibrous casings. Drying and smoking take place at temperatures around 60–70 °C and the product is then generally cooked with steam at 70–75 °C to an internal temperature of only 45–48 °C. After cooling, the product is placed in a freezer until its temperature falls to between approximately –1 and 0 °C, which improves sliceability of this (essentially) raw product. The sliced product is sold vacuum packed. Recently waterproof casings have become more common, and these products are fully cooked with steam or in a water bath at 78–80 °C until a core temperature of 70 °C is reached. This bacon contains the whole gamut of additives, and smoke flavour is frequently added to the brine to provide a touch of smoke in this non-smoked product. The fully cooked product is then sliced and vacuum packed.

### 9.3 Cooked ham on the bone (Australia)

Cooked ham on the bone is made from the entire pork leg and in most cases the aitchbone (pelvic bone) is not removed. The leg is injected at around 30–35% and common additives are phosphates, salt, nitrite, erythorbate, some sugars and occasionally some flavour. Carrageenan is used quite frequently, to a level of around 2–3 g per kilogram of finished product, and the amount of salt is around 20–24 g per kilogram of finished product. The injected leg is generally soaked in a cover brine for around 12–48 h as described in Section 9.1. Afterwards, the legs are placed in elastic nettings and hung on smoking sticks; so the netting carries the weight of the leg. After drying at around 60–70 °C for 1–2 h, the meat is smoked for 1–2 h at 70–75 °C and then cooked with steam at 74–78 °C until a core temperature of 66–70 °C is reached. A cooking yield of around 110–115% is the norm and the chilled product is vacuum packed as a whole piece or cut into halves or thirds.

Core temperatures are a constant point of discussion as quite a few manufacturers claim that a core temperature of 66 °C is sufficient. Lifting the core temperature of a large leg from 66 °C to, for example, 69 °C takes a long time and several per cent in weight are lost during this prolonged period of heat treatment, which is an important economical consideration. From a microbiological point of view, a core temperature of 66 °C might be sufficient as high *F* values are obtained because of the time taken to reach 66 °C in the core (generally between 8 and 14 h of cooking, depending on the size of the leg) and the fact that the core temperature of 66 °C is commonly held for around 30 min. However, reaching 66 °C is insufficient for the complete denaturation of nitrosomyoglobin and so curing colour could

fade or grey in the finished product. In addition, commonly used types of carrageenan are not solubilized at 66 °C and the non-solubilized material will not form a gel upon cooling; so the full benefits of using such an expensive additive are not obtained. Cooked hams on the bone are traditional Christmas hams and untreated pork legs are placed into the freezer all year round to ensure a sufficient supply for the production of such hams for the Christmas season.

#### **9.4 Champagne ham (Australia)**

Champagne ham is made from boneless whole muscles from pork leg, well trimmed and all fat removed. The level of injection is around 40–50% and the additives commonly used are phosphates, salt, nitrite, carrageenan, erythorbate, different flavours and occasionally soy isolate. The finished product contains around 20–22 g of salt per kilogram of product, maximum nitrite of 125 ppm (nitrite and nitrate), 2–5 g of carrageenan per kilogram of product and 5–10 g of soy (if applied) per kilogram of product. Flavours such as HVP, juniper and others are frequently introduced as well. The injected meat is frequently tenderized and tumbled under vacuum for around 4000–5000 rev. The tumbled meat is predominantly filled into large-diameter fibrous casings and hung inside a plastic netting on smoking sticks so that the netting carries the weight and the product does not develop a pear shape. The hung product is then dried at 60–65 °C, smoked at 65–70 °C and finally cooked with steam at 76–80 °C until a core temperature of 69–70 °C is obtained. Cooking yield is around 135–140% and the product is predominantly sold sliced and vacuum packed or, increasingly, shaved and modified atmosphere packed.

#### **9.5 Master ham (Austria)**

There are countless different types of master hams on the market as almost every owner of a ham company originates his own version of this type of ham. A common version of master ham is made from pork leg, knuckle removed, skin and fat on and completely deboned. Legs are selected that have a thin layer of fat. After careful deboning, the topside is removed and the leg is trimmed to obtain a heart-shaped piece of meat. The level of injection is low, around 20–25%, and additives used include phosphates, salt, nitrite, colour enhancer and flavours such as garlic, juniper or even red wine. The finished product contains around 18 g of salt per kilogram of product. No carrageenan, protein or starch is used. After injection, the meat is gently tumbled under full vacuum for around 2000 rev so that the natural binding between the individual muscles is not destroyed and then placed

horizontally on grid racks with the skin side down. The meat is then dried at 60–65 °C until a dry surface is obtained, smoked at 65–70 °C and then heated in steam at 76–78 °C until a core temperature of 68–70 °C is obtained. Occasionally, the product is treated in the final stages of cooking with dry heat instead of steam to obtain a strong colour and flavour. The cooking yield of such a product is around 110%.

## **9.6 Kasseler (Austria and Germany)**

Kasseler is a traditional ham product and primarily eaten together with sauerkraut and dumplings. The pork loin, boneless or bone in, skin and fat removed, is used in a very similar way to that of a master ham (see above) with the additives used being more or less the same. The prepared loin is injected at 15–25% and occasionally slightly tumbled afterwards for around 500 rev. Tumbling is more common for boneless loins, as the bones in bone-in products damage the other pieces of meat during tumbling. Non-tumbled meat is frequently placed in cover brine for 12–24 h before being hung. The next stage is drying at 60–70 °C, followed by smoking at 65–70 °C and finally cooking with steam or a hot-water bath at 74–78 °C until a core temperature of 68–70 °C is obtained. The chilled product is sliced and usually vacuum packed. Restaurants serve the slices hot with dumplings and sauerkraut.

## **9.7 Virginia ham (Australia)**

Boneless whole-muscle meat is taken from the legs and all fat and skin is removed. Occasionally, lean muscle meat from pork shoulder is used for more economical types of Virginia ham. The level of injection is between 50% and 80% and functional additives such as phosphates, salt, carrageenan, soy protein and injectable starch are commonly used together with additives such as nitrite, erythorbate and sugar. The finished product contains around 5 g of carrageenan per kilogram of product, 10–15 g of soy protein per kilogram of product and 10–30 g of starch per kilogram of product. Colours such as fermented rice or cochineal and flavours are generally used to compensate for the high level of extension. The finished product also contains around 24 g of salt per kilogram of product, balanced by around 10–15 g of sugar per kilogram of product. The brine used is frequently quite thick because of the large amount of dry additives that it contains. The meat is heavily tenderized to increase surface area as much as possible, and this is normally done with a knife tenderizer, which almost cuts it into smaller pieces. The tenderized meat is placed in a tumbler and 5–10% of lean minced meat is added before tumbling begins. Tumbling at 5000–6000 rev is applied under full vacuum and the tumbled meat is generally filled slightly loosely

into large-diameter fibrous casings. The underfilled products flatten slightly as they are placed, or pressed, into metal grid cages. This pressing produces an oval-shaped finished product. The cages are generally hung and the product is dried at 65–70 °C, smoked at 70–75 °C and steamed at 74–80 °C up to a core temperature of around 70 °C. After thermal treatment, the product is showered for around 20 min before being placed in the chiller. The cooled product is typically sliced and vacuum packed, although some Virginia ham is shaved and modified atmosphere packed. Whole pieces are sold to delicatessens and sliced to order. A Virginia ham is an economical whole-muscle pork ham and the cooking yield varies between 150% and 180%.

## 9.8 Bacon (England)

Bacon is an important product in the UK and almost every county or region has its own typical bacon. English bacon is made from primals of pork such as middle, loin, belly or fore-end. Wiltshire bacon is produced in three distinctive stages, with injection being the first step. The level of injection is around 10–15% and freshly prepared brine is used. Additives generally used are salt, nitrite, nitrate, phosphate, colour enhancer and dextrose, brown sugar or maple syrup. The maximum concentration of nitrite allowed at point of sale is 175 ppm per kilogram of product and the maximum concentration of nitrate is 250 ppm per kilogram of product.

The injected meat is placed into a 'live' immersion brine for around 2–3 days. Live brine is almost saturated and contains around 22–24% salt, nitrite at 0.1–0.2% and nitrate at around 0.4%. The high concentration of salt supports the growth of a certain microflora, which helps the breakdown of nitrate to nitrite and also produces desirable flavours. Care must be taken that the microbiological stability of the live soaking brine is maintained, and salt and nitrite are regularly added to the brine to make up for the losses when freshly injected meat is placed in it. Some of the brines used for making bacon are years old and contain a blend of bacteria which gives a very distinctive flavour to the bacon. The bacteria count of a live brine can be as high as  $10^8$  per millilitre of brine and the pH is between 6.0 and 6.4. Microbiological stability of a live brine is maintained by controlling the levels of salt, nitrite and nitrate, and the composition is checked regularly. Temperature must also be controlled, and the brine is kept cold at all times and only well-chilled injected meat is placed in it. The brine is kept agitated, or aerated, if it is not used for several days in order to introduce oxygen, but normally the addition and removal of meat generates enough movement to keep the brine aerated. Starter cultures are becoming more common as they enable manufacturers to prepare live brines quickly and to remove the need to check and monitor an old brine.

In the final step, soaked meat is removed from the live brine and matured for around 4–6 days at 3–5 °C. In the past, maturing sometimes continued

for up to 2 weeks. During maturing, the salt introduced into the meat evens itself out and the curing flavour develops.

Generally, bacon in the UK is sold unsmoked (green) and sliced bacon is commonly packed under a modified atmosphere. The gas mix consists generally of 30–35% CO<sub>2</sub> and the remainder is nitrogen. The level of salt in bacon is around 3–3.5%. Sea salt is the predominant choice for salt. In the past, typical Wiltshire bacon was made by submerging an entire side of a pig, head removed, into a live brine without injection and the cured meat was deboned afterwards. Other methods of producing bacon in the UK are to inject pieces of pork and then to place the injected pieces of meat in a cover brine. A cover brine has similar concentrations of additives as the injected meat, and soaking normally lasts for 2–3 days. Yet another way to produce bacon is to place the injected meat in waterproof bags after soaking in the cover brine for around 24 h, and equilibration of additives and curing continues inside the bag. After several days, the cured meat is removed from the bag, sliced and packed, with the product being kept at 2–5 °C during all the processing steps.

## 9.9 Bacon (USA)

Bacon in the USA is generally produced from boneless pork belly. Bellies, if sold under the term bacon, cannot yield more than 100%, which is the raw meat weight, and therefore no extension is possible in the finished product above green weight.

Commonly, bellies are injected at 11–14% with additives such as phosphates, salt, nitrite, erythorbate, sugar and flavours. Cover brine is not normally used, and the injected bellies are dried, smoked and cooked at 55–58 °C to a minimum core temperature of 53 °C. Occasionally, a cover brine is used, with the injected bellies being submerged for 12–24 h. Thermally treated bacon is then cooled, often pressed into a clearly defined rectangular shape, then sliced and predominantly vacuum packed. Belly bacon is also produced by dry curing, and salt, nitrite and antioxidant is rubbed on to the surface. The salted pork belly is placed for 7–10 days under cold conditions, below 5 °C, so that the curing colour can develop and the salt spread evenly throughout the meat. The product is then commonly cold smoked at 20–25 °C, slightly frozen and formed, sliced and vacuum packed.

## 9.10 Pastrami (USA and Australia)

Pastrami in Australia is commonly made from the eye of silverside whereas, in the USA, silverside is most commonly used. Occasionally, beef brisket is used in the USA, and enzymes, commonly papain, are included in the injection

brine because brisket is a tough meat and the enzymes help to tenderize it. Generally, the level of injection in Australia is between 25% and 35% while 30–40% is the norm in the USA. In both countries, the basic additives injected are phosphates, salt, nitrite and erythorbate, with the final product containing around 2–2.2% salt.

The injected pieces of meat are frequently tumbled a little in both countries, to tenderize the meat and to activate some of the internal protein as well as that on the surface. Carrageenan and soy are not generally used to increase yield. Typically, spices are applied to the lightly tumbled meat, which is then hung. Products with spice coatings are dried at 60–70 °C, occasionally smoked for a short while at 65–75 °C and then steam cooked at 75–80 °C until a core temperature of 70 °C is obtained. In the USA, products which do not have spices on the surface are not smoked but are packed after light tumbling into a cooking foil, or cooking bag, and thermally treated with steam to a core temperature of 72 °C. The final cooking yield for pastrami products in both countries is around 110%. The cooled product is sold to delicatessens in whole or half-pieces, or sold sliced or shaved to retail shops. Sliced or shaved products are either vacuum or modified atmosphere packed, with modified-atmosphere packaging having around 25–35% carbon dioxide and 65–75% nitrogen.

### **9.11 Roast pork (Australia)**

Roast pork is generally boneless pork forequarter meat. High-quality roast pork is injected at 15–20%, while more economical products are injected around 40–50%. When injection is low, additives such as phosphates, salt, some flavour and guar and xanthan gum are introduced to keep the injected brine within the meat, as roast pork is generally sold in a raw (uncooked) state and the consumer prepares the dish at home. Salt is normally present at 14–16 g per kilogram of product but, as considerable loss in weight takes place during roasting, the levels of salt rise to around 20–22 g per kilogram in the roasted product. Roast pork is an uncured meat product and no nitrite is added. Cold-swelling gums such as guar and xanthan gum are applied at around 0.2–0.4 g of each, or a combination of both, per kilogram of injected meat, and care must be taken to ensure the brine does not become too viscous for easy injection. Injected meat is most commonly tumbled for around 500–800 rev before being either vacuum packed or placed on trays and wrapped with foil. More economical roast pork is basically the same except that extra additives, such as injectable proteins and starch, are used to keep the elevated levels of brine in the injected product. This type of meat is tumbled for around 800–1000 rev before being packed, and again no nitrite is applied. The product is sold in an uncooked raw state and the end consumer cooks it. In both cases, flavours such as garlic and pepper are added to the brine before injection.

## 9.12 Beef bacon

Beef bacon is commonly produced using deboned beef brisket, which is 20–35% injected. The additives used are phosphates (5 g per kilogram of meat), salt (18–22 g per kilogram of meat), nitrite (150–250 ppm per kilogram of raw uncooked injected meat), ascorbate (0.4–0.6 g per kilogram of meat) and sometimes flavours as well. Following injection, the meat is generally soaked for 12–48 h in a cover brine containing around 3% salt as well as 300 ppm of nitrite per litre of brine, although sometimes the injected meat is processed immediately after injection. Subsequent treatment includes hanging the injected brisket on trolleys and drying it at 60–70 °C, smoking at 65–75 °C and finally steam cooking at 75–80 °C until a core temperature of 70 °C is reached.

It should be noted that the term ‘bacon’ refers only to pork in some countries (e.g. England). However, in other parts of the world, this term is used more generally for any meat.

## 10

### **Re-formed products: non-injection methods for adding brine**

Added-brine hams are made by adding brine to minced meat, mixing and then heat treating the mixture. Three different quality levels are produced.

- 1 High-quality products consist of large pieces of pork, chicken, turkey or beef. Lean pieces of meat are minced with a large-diameter blade or just passed through the mincer worm. The level of extension is generally between 25% and 40%.
- 2 Medium-quality products are made from smaller pieces of minced lean meat, mostly lean trimmings, and a mincer blade of 2–4 mm diameter is commonly used. This type of product is commonly extended by 50–100%.
- 3 Economy-quality products are commonly extended between 70% and 140% and the raw materials used are a combination of lean meat trimmings, pork or chicken skin emulsion and hard or soft MDM.

The level of extension is based on counting the raw materials as 100%. For example, if 80 l of brine are added to 100 kg of lean minced meat, the extension is 80% and the total, or final, cooking yield is 180% (assuming that the product is filled into a waterproof casing and there is no cooking loss during heat treatment). The 100 kg of raw materials could also consist of 70 kg of lean minced meat, 20 kg of MDM and 10 kg of skin emulsion. An extension of 120% results in a yield of 220% and, to achieve this, 120 kg of brine would be added to 100 kg of raw material.

It should be noted that the term ‘ham’ in some countries (e.g. England) refers only to pork but in the rest of the world it is used for countless meat products where brine is added to smaller pieces of meat. In countries where pork cannot be eaten, many different types of ‘ham’ are produced which are made from a variety of meats other than pork.

## 10.1 Selection and preparation of raw materials

The meat to be processed should be as lean as possible. Material that is 85–95% chemically lean (CL) is generally used (a 90% CL material consists of 90% lean meat and 10% fat). Pork is the most commonly used meat, but any other type of lean meat can be used as well, and sometimes even fish is used for manufacturing added-brine hams. Another way to grade meat is visual lean (VL). However, there are often large variations in fat content in VL meat; so CL materials are preferred in order to maintain a standardized level of fat in the product. The meat material should be free of any visible fat, or have the smallest amount of fat possible, as visible particles of fat are not appealing to the consumer.

The meat should be well chilled, with an optimal temperature of 0–4 °C. The bacteria count of the meat should be as low as possible and is usually around  $10^2$ – $10^4$  per gram of meat. A pH between 5.7 and 6.1 is preferred, as higher pH results in increased solubility of proteins (WBC) and enhanced WHC. The worst WHC in meat is at the IEP at a pH of 5.2. At a pH between 5.7 and 6.1, the protein will have unfolded significantly because electrostatic repulsive forces within the protein molecule create larger gaps between actin and myosin and therefore more water can be immobilized within the molecular structure. Frozen meat must be fully thawed prior to processing, and there must be no frozen areas in larger pieces of meat (see Chapter 4, Section 4.7).

The meat is minced with the desired size of blade. Blade size commonly ranges from 3 to 20 mm. The meat is sometimes only minced with the kidney blade so that larger pieces can be seen in the finished product. A combination of different materials is frequently chosen and more fatty meat is generally minced with a small blade, while lean meat is minced with a larger blade. This differential mincing makes the final product appear lean ham because the more fatty cuts are hidden by fine mincing. If lean meat is minced with a blade diameter of 10–20 mm, then the mincer contains a single set of knives. A single set, starting from the end of the worm (spiral), is arranged in the sequence precutting or kidney blade → knife → blade (10–20 mm) → fixation ring. If the desired particle size is 2–8 mm, a double set is normally used, and the sequence of knives and blades, starting from the mincer worm, is precutting or kidney blade → knife → 13 or 20 mm blade → knife → final blade (2–8 mm) → fixation ring. A double set of knives is used because mincing larger pieces of meat directly down to a particle size of 3 mm causes enormous friction, and a clear cut is obtained by using a double set of knives. It is vital that the meat is cut cleanly during mincing; tearing and smearing should be avoided; so all blades and knives must be clean, sharp and tightly adjusted. Cutting the minced meat cleanly helps to avoid a rise in temperature, as does mincing at moderate speeds. If the meat is exposed to tearing and high shearing forces during mincing, its temperature can rise significantly, resulting in microbiological risk.

Fatty trimmings can be hidden inside the finished product by making an emulsion in the cutter from meat and brine, which is achieved by cutting both together for a short while under a slow to medium knife speed. The emulsion is then added to the minced meat and brine.

In very-low-cost products, the use of MDM and MSM (see Chapter 4, Section 4.2) and skin emulsion (see Chapter 12, Section 12.2) is an everyday occurrence. A mixture of around 30% MDM and 70% minced meat of 85–95% CL grade, extended between 50% and 80%, still gives an acceptable product. Chicken or pork skin emulsion is commonly used as well; so a low-cost recipe could contain 20–30% of MDM, 10–15% skin emulsion and 55% finely minced meat of 85–95% CL grade. Countless combinations of different CL-grade meats with or without skin emulsion and/or MDM generate the raw material base for low-cost products. If hard MDM is used, it must not be rancid. Soft MDM can be processed without problems as long as the bacteria count is at an acceptable level.

Added-brine hams are eaten cold predominantly, and the addition of skin emulsions, whether pork or chicken, adds firmness to the finished product. Skin emulsions are economical to produce and are frequently used in products where the lean meat is minced with a small blade (2–4 mm diameter). The use of different mincer blades, in combination with different types of meat, increases the number of possible raw material combinations even further, and therefore the number of possible finished products.

Added-brine poultry products generally contain breast and thigh meat together with chicken skin emulsion. In most parts of the world, products made from chicken should be white because the whiteness is associated with a healthy image by a large percentage of consumers. The addition of skin emulsion lightens the colour of the finished product, and a combination of breast meat and chicken skin emulsion literally results in a white product.

High-quality chicken products are made from chicken breast alone. The meat is minced with a coarse blade (13–20 mm) or the kidney blade alone, and the level of extension is generally between 40% and 80%. The level of extension on high-quality added-brine hams is approximately 30–50%, and the large lean pieces of meat are minced with the kidney blade alone or passed through the worm twice without using a blade. This treatment tears the large pieces of meat apart and so plenty of muscle surface area is obtained without having to inject, and the finished product material has an almost whole-muscle appearance.

## 10.2 Selection of additives

The choice of additives and the amount used depends on the desired level of extension. As most added-brine hams are filled into waterproof casings, the type and level of additive must ensure that there is no water or fat separation in the product after heat treatment. Additives such as phosphates, salt, sugars,

nitrite (mostly for pork and beef products) and ascorbate are almost always added at the same amount per kilogram of total mass, regardless of the level of extension. Additives such as carrageenan, protein and starch are adjusted according to the level of extension required in the final product. The total mass consists of the meat materials and the added brine. For example, if 80 l of brine are added to 100 kg of meat, the total mass is 180 kg and the amounts of the different additives are calculated on the basis of those 180 kg. Phosphates, which dissolve readily and fully in cold water, are used at 3–5 g per kilogram of total mass, while salt is usually between 16 and 24 g per kilogram of finished product. Nitrite is generally introduced at 180–250 ppm per kilogram of total mass but is adjusted to the level of nitrite permitted in the finished product under food regulations. Generally, around 40–60% of the nitrite added to the raw ham mass is not present in the finished product. More specifically, if 200 ppm of nitrite per kilogram of total mass are added, typically around 80–100 ppm will be found as residual nitrite in the cooked product. Ascorbate or erythorbate is used as a colour enhancer in cured products, at 0.4–0.7 g per kilogram of total mass. Ascorbic acid must not be used as the colour enhancer because, if it is added to brine containing nitrite, the two compounds will react. When nitrite and ascorbic acid come into direct contact, an instant chemical reaction takes place resulting in the formation of nitrogen oxides ( $\text{NO}_x$ ). The main nitrogen oxides formed are nitric oxide (NO) and nitrogen dioxide ( $\text{NO}_2$ ), both of which are toxic. High levels of salt are often used because salt helps to activate proteins, and sugars, such as dextrose and sucrose, are frequently added to cover up the salty taste. Sugars typically range between 5 and 15 g per kilogram of finished product. Other additives have to be adjusted according to the level of extension.

Table 10.1 illustrates types and amounts of additives regularly used for different levels of extension, together with additives that are present at any level of extension.

Because added-brine hams are often highly extended, the original colour and flavour of the meat are diluted. To compensate for these losses, flavourings and colours such as fermented rice, red wine extract, allura red, beet red or carmine are often used (see Chapter 6, Section 6.13). High amounts of added water also reduce the firmness of the product, and this is compensated for by adding pork rind powder (see Chapter 6, Section 6.1.7) to around 5–20 g per

**Table 10.1** Additives commonly used in brine-added ham

Level of extension (%)	Carrageenan (g per kg of total mass)	Protein (g per kg of total mass)	Starch (g per kg of total mass)	Pork rind powder (g per kg of total mass)
50	2	5	30–40	0
80	3	10	50–60	0
100	4	15–20	50–60	5
120	5	20–30	60–80	10–15

kilogram of total mass. The addition of pork rind powder also enhances the meat-content of the product, as most countries classify pork skin as meat.

The starch is usually whatever is locally available because this is cheapest, and soy protein is the predominant choice of proteins. If soy protein is not acceptable or desired, whey protein or gluten are alternatives. However, soy protein also improves the texture of an added-brine ham, because of its ability to form a gel, especially at high extensions. A non-injectable soy protein can be used, and the amount added varies generally between 1% and 3% (between 10 and 30 g) calculated per kilogram of finished product, depending on the level of extension. Greater amounts of soy are used for higher levels of extension. Carrageenan does not have to be injectable grade either, as blocking of filters or needles is not an issue.

Smoke flavour can be added to the brine if required, and 0.1–0.5 g of smoke flavour per kilogram of total mass is generally sufficient. Lactate is commonly added at around 30 g per kilogram of total mass, because high levels of extension automatically mean high levels of water in the finished product, which would otherwise promote the growth of bacteria. Lactate improves shelf life, particularly in products with a high water content, because of its growth-inhibiting properties (see Chapter 5, Section 5.2.2). Citric acid or GDL should not be used to extend the shelf-life of the finished product, because both substances release hydrogen ions ( $H^+$ ) which could react with nitrite, depending on concentration. As a general rule, no acids should be added to a brine containing nitrite. If sour additives are used to improve shelf life, they only have a real impact if they reduce the pH in the meat itself, and this drop in pH also has a significant negative impact on the WHC of muscular protein, reducing firmness and texture. In extreme cases, an excess of sour additives in the brine results in water separation during thermal treatment.

## 10.3 Manufacturing technology

### 10.3.1 Preparation of the brine

It is essential that the brine contains all additives needed in amounts that correlate with the levels required in the finished product and no water or fat separation takes place during heat treatment. Using compounds, or premixes, instead of individual additives simplifies the process of preparing a brine tremendously and reduces storage requirements. Most often a compound, or complete cure, is used, which contains all additives except salt. Salt is generally added by the manufacturer separately, as it can be bought at low cost on its own, although some manufacturers prefer to buy compounds that include salt as well to avoid human error in making up the brine. Many manufacturers obtain their brine compounds tailor made to specified levels of extension, flavouring and colour. The compound is dissolved or dispersed first in cold water. Once it is fully dissolved, the salt is added in cases where salt is added separately. If individual additives are used, the sequence of adding them to

the water should be phosphates → soy protein → starch → salt → carrageenan. Phosphates require the highest amount of free water in order to dissolve fully and are therefore added first. Other additives, such as pork rind powder, colour enhancer (erythorbate or ascorbate), colours and flavours can be added at any stage but not before the phosphates. Lactate, if used, is the last additive to be added to the brine, after the salt is fully dissolved. Premixing of some additives, such as starch with sugar or carrageenan with sugar, enhances dispersibility. As a rule of thumb, premixing of a fully soluble additive, such as sugar, with non-soluble materials such as starch, soy or carrageenan, enhances dispersibility of dispersible materials greatly. When premixing dispersible materials such as carrageenan and starch with soluble materials such as sugar, the premixed materials are all added before the salt, and salt must be the last material to be added to the brine (besides lactate, if lactate is added). The ingredients of compounds dissolve and disperse readily in cold water if they are mixed sufficiently, and the dispersibility of non-soluble materials is enhanced because they are combined with soluble materials.

The water used to make brine must be cold. Chilled water, which has passed through heat exchangers and has a temperature range from 0 to 3 °C, is ideal but, if the only water available is ordinary tap water, ice is used to lower the temperature. Some of the ice should be added to water before any additives, to lower the temperature to around 6–10 °C. Once the compound, or additives, and salt are fully dissolved, the remaining ice is added to bring the temperature down to between –1 and 2 °C. No ice cubes or flakes of ice should be present in the water when the additives or compound are added, because those that only disperse, such as soy protein, would freeze on the ice and functionality would be significantly reduced.

The finished brine must not have any lumps of starch or any other additive. The temperature of the brine can be as high as 6–8 °C if some of the minced meat material is still slightly frozen, but this should be the exception and normally, well-chilled meat is processed with a cold brine. It is essential that the total mass, meat and brine, has a temperature between 0 and 3 °C before mixing commences. This temperature range is vital for the proper activation of protein, because myosin and actin have the highest solubilities at temperatures between 0 and 4 °C. The low temperature also helps to prevent growth of bacteria.

### **10.3.2 Tumbling and mixing**

One method of combining the meat materials with the brine is simply to place the meat in the mixer and to add the brine directly to it. This is the method commonly used when no materials such as MDM or skin emulsions are included. If the recipe does contain MDM and skin emulsions, the brine must be introduced evenly, and this is done by cutting these materials in a bowl cutter while gradually adding the brine. Cutting takes place at slow speeds of around 500–800 rev/min, which is just enough to introduce the

brine evenly into the MDM and skin emulsion. This additional step helps to avoid any lumps of MDM or skin emulsion in the finished product, and around 20–30% of the total brine is added to MDM and/or skin emulsion in this way. The slurry, consisting of MDM, skin emulsion and some brine, is then added to the other minced meat material and brine in the mixer. Cutting the MDM and skin emulsions can be omitted if the mixing machines used are highly efficient and eliminate all possible lumps.

Low-cost added-brine hams are typically composed of 20–40% MDM, 10–15% skin emulsion and around 50% meat as the basic mixture, which is then extended by 100% or more. They are commonly made by cutting all materials, MDM, skin emulsion and meat in a bowl cutter at a slow speed for a few cycles while adding all the brine. Once all the brine is evenly mixed in, and the meat particle size is around 2–3 mm, the mixture is removed from the bowl cutter and placed in the mixer.

Mixing, rather than tumbling, is the predominant method for introducing energy into the ham mass for added-brine hams. Slow-moving paddles, or mixing arms, inside the mixing machine keep working on the meat mixture. The barrel, or container, is stationary and only the paddles move. Tumbling is a process where the container, or barrel, turns around its own axis and the container is not stationary (see Chapter 8, Section 8.4.4.). Highly extended added-brine hams are not normally tumbled because the finely minced meat and high levels of additives produce an extremely tacky mass, which would stick to the walls of the tumbler and therefore not be mixed properly. The paddles or mixing arms in a mixer work much more effectively on the meat mixture, activating high levels of protein due to the amount of mechanical energy introduced and causing swollen muscle cells to burst.

Three different methods of mixing are common (see Chapter 8, Section 8.4.4).

- 1 *Interval mixing.* This method is similar to interval tumbling. The mass is mixed for a certain period of time and is then left to stand (rest) for a while and is then mixed again. The mixing time is usually around 20–30 min and the resting period brings the total cycle to 1 h. The mixing–resting cycle is repeated over a period of 10–14 h under full vacuum.
- 2 *Split mixing.* The brine and meat are mixed continuously under vacuum for approximately 3–4 h. The resulting mass is then removed from the mixer and placed in the chiller overnight. Next morning, the meat mass is mixed again, continuously, for an additional 1–2 h under full vacuum. This method means that the mixing machine can be used overnight for other products to be mixed and is not occupied for 10–16 h by one batch.
- 3 *Continuous mixing.* Gentle and continuous mixing under vacuum for 5–6 h is the third method. The mixture is then removed from the mixing machine and placed overnight in the chiller to allow the colour to develop. The meat mixture is then filled the following morning, without any further mixing treatment.

With all three methods, the total mixing times are more or less the same and there is no significant difference in the textures, firmnesses or colours of the finished products. However, firmness is slightly less using the continuous-mixing method. Proteins swell over time, and mixing for 5–6 h continuously damages muscle cells to a lesser degree because less time is allowed for swelling. The cells that swell during resting in the chiller are not activated effectively because there is no further mixing, or input of mechanical energy. More specifically, the sarcolemma of the swollen muscle cells is not destroyed efficiently and so the amount of solubilized proteins released is insufficient.

Care must be taken to ensure that the temperature of the continuously mixed meat mass does not rise above 5 °C, to prevent growth of bacteria. The mixture is commonly placed in large trollies after it is removed from the mixing machine. If the temperature of the mixed ham mass is high once it has been removed from the mixture, the meat mass requires a long period of time for its core to drop to a temperature below 5 °C. Souring and microbiological spoilage are a problem if the temperature of the core of the ham mass stays high for a prolonged period of time in the trolley. To help to lower the temperature, carbon dioxide (CO<sub>2</sub>) can be introduced into the mixing machine shortly before the end of the 5–6 h mixing period, so that the meat mass is at 0–2 °C when it is removed.

Added-brine hams, which contain large pieces of meat as they are minced with the kidney blade or worm, are normally tumbled. This type of ham is generally of higher quality and the extension is only 30–40%. Working with larger pieces of meat justifies the use of a tumbler as tumbling does not reduce the size of the meat pieces during tumbling and protein is activated effectively. Tumbling under full vacuum lasts for around 3000–4500 rev, to maximize the amount of solubilized protein and to avoid formation of foam. The tumbling can be achieved by one of the three methods described (continuous, split tumbling or interval tumbling). Using a paddle mixer would destroy the large pieces of meat; so it is not appropriate when the characteristic appearance of a whole-muscle product is desired.

Whether mixed or tumbled, the process should be carried out in a cold environment (between –1 and 2 °C). This keeps the temperature in the ham mass between 0 and 4 °C for maximum activation of protein and inhibition of bacteria (Chapter 8, Section 8.4.4).

Applying a strong vacuum, –0.8 to –0.95 bar or more, during mixing or tumbling is advantageous. Under a vacuum, proteins swell better, curing colour develops faster and the curing flavour becomes stronger. Increased swelling means that more protein is activated, which immobilizes added brine more effectively, leading to a firmer product and reducing the level of purge in sliced packed products. The removal of oxygen and the lack of pressure inside the mixing device mean that NO, obtained from nitrite, can bind more quickly and more effectively to myoglobin, which creates a stronger curing colour (see Chapter 7, Section 7.3). Development of the curing colour

depends largely on the size of the meat particles and the temperature under which the mixed mass is stored. For meat particle sizes between 2 and 13 mm, a period of 10–12 h at around 2 °C is sufficient for a strong curing colour to develop. Larger pieces of meat, treated with the 20 mm or kidney blade, need about 12–14 h at around 2–4 °C for proper colour development. Mixing under a vacuum also prevents formation of foam, contributing to good slice coherency.

Some added-brine ham is produced by mincing meat with a 2 mm blade, adding brine and then mixing for around 3 h under vacuum. After mixing, the ham mass is left standing for 3–4 h before being filled and cooked. This type of product also has a strong curing colour because the particle size is very small; so there is a large surface area for the nitrite to work on and colour development is completed within a short period of time. The gradual increase in temperature during cooking of the product is generally sufficient to generate enough NO and to form nitrosomyoglobin, which is subsequently denatured to form the stable nitrosomyochromogen.

### 10.3.3 Filling

The highly tacky ham mass should be filled using a vacuum filler to eliminate all remaining air trapped inside. Air pockets reduce firmness, cause discolouration and encourage the separation of fat where fatty meat is included in the raw material. The largest possible filling pipe should be used to avoid squeezing the ham mass as it passes through the pipe. The speed of filling should be moderate to avoid air pockets, and the ham mass should be filled tightly into the chosen type of casing. The filling pipe should also be as short as possible, again to avoid squeezing.

Waterproof casings are mostly used for added-brine ham, and the treatment of the casing prior to filling is determined by the type of casing. Some casings can be filled 'dry', without any soaking prior to filling. Waterproof casings are often used for ham that has been processed in square or rectangular moulds, and the finished product is commonly sold as 4 in × 4 in or 4 in × 6 in ham, based on the size. Square and rectangular hams fit perfectly on sliced bread and are predominantly used for sandwiches. A D-shaped product is obtained by filling waterproof casings up to around 70% and placing them horizontally on racks to let the shape form.

Large-diameter products, which are made from large pieces of meat minced with the 20 mm mincer blade or passed through the worm, are filled into fibrous casings, collagen foil and netted or filled into moulds. Fibrous casings need to be soaked for around 20–30 min in lukewarm water if unprinted, and for around 50 min prior to filling if printed. Moulds should be lined with a layer of plastic to prevent the meat from sticking to the mould during thermal processing (see Chapter 35, Section 35.2). All casings have to be filled tightly or up to the recommended filling diameter to maintain the shape and to avoid wrinkling. Casing manufacturers provide instructions for each type

of casing. Waterproof casings with good reshrinkability not only prevent wrinkling, but also help to avoid water separation during cooking and cooling. Some fibrous and waterproof casings have a layer of smoke additive on the inside to give smoke flavour and colour to a non-smoked product.

The casings must be clipped carefully so that the clips do not split the casing but are tight enough that they do not move during cooking. A certain amount of tension is needed on the product for firmness and texture and to maintain the correct diameter.

#### 10.3.4 Cooking and cooling

Cooking or thermal processing of added-brine ham should start at the earliest 12–14 h after the brine was added to the meat. Colour development takes place quickly in products made out of meat minced with the 2–3 mm blade. These products contain finely minced material and so generally 6–8 h is sufficient. When meat has been minced with a coarser blade, sufficient time is needed for the curing colour to develop, and colour development is slow owing to the low temperatures of both the meat mixture and the brine. Added-brine hams in waterproof casings or moulds are most commonly cooked in steam or a water bath at 76–80 °C until the core temperature reaches 70–72 °C. Some processors base their cooking process on reaching a specified  $F_{70}$  value (see Chapter 40). Cooking is carried out predominantly at a constant temperature because this is the fastest method, and products in waterproof casings do not lose weight during cooking. Step or  $\Delta T$  cooking (see Chapter 8, Section 8.47) is not common as the longer cooking time does not benefit the finished product significantly.

Products filled into fibrous casings, collagen foil or netting are normally dried for approximately 30–60 min at 60–65 °C, smoked at 65–70 °C until the desired smoke colour is obtained and then cooked at 76–80 °C until the desired core temperature, commonly between 70 and 72 °C, is reached. Products made from larger pieces of chicken or larger pieces of pork, which have been passed through only the precutter or kidney blade or passed through the worm twice, are often filled into fibrous casings and smoked prior to cooking as well. If the casing utilized has a layer of smoke additive on the inside, the first processing step after filling is to dry the product at around 70 °C for roughly 1 h. This ensures that the colour of the casing transfers effectively on to the surface of the ham product because the activated protein on the meat's surface absorbs the smoke additive. Dry heat should be used for this step, because moist heat (steam or water bath) would result in an uneven colour. Once the smoke colour is fixed by dry heat, then cooking with steam or a water bath can commence.

Consistency and texture of added-brine hams are significantly different if, for example, the amount of brine added is 50% and a waterproof casing is used, compared with 60% brine and a fibrous casing. Cooking yield for the ham in a fibrous casing will be around 150% after drying, smoking and

cooking because some moisture will be lost, which is the same as the yield for the 50% ham in a waterproof casing. Products in fibrous casings normally have a firmer consistency and a more distinctive ham flavour. A 150% yield ham in a fibrous casing has better sliceability than a 150% ham filled in a waterproof casing. This is because substances such as formaldehyde in the smoke can permeate the fibrous casing and react with the protein on the surface of the ham, which results in a thin, but solid, layer on the surface, making the product easier to slice.

Moulded products are heated in steam or a water bath at 74–80 °C until a core temperature of around 70–72 °C is reached. Once the desired core temperature, or  $F_{70}$  value, is obtained, the product should be cooled quickly. This is normally achieved by showering the product with cold water for around 10–15 min upon removal from the steam or hot-water bath and then placing the moulds in a blast chiller. Some waterproof casings do not need to be showered, whereas other casings must be showered with cold water for between 5 and 30 min. Showering at intervals is beneficial (see Chapter 8, Section 8.4.9).

The showered product is then placed in chillers or blast chillers (around 0 °C) in order to reduce the core temperature to below 10 °C quickly, and then more gradually to below 4 °C. It is important to cool the meat quickly from 55 to 10 °C because surviving spores could germinate if cooling takes place too slowly. A temperature below 4 °C is effective against surviving bacteria such as *Salmonella* spp and *Staphylococcus aureus*. In addition, the gels that form from dissolved protein, carrageenan and starch set more effectively if cooled quickly. The product should not be squeezed or put under pressure, for instance by being stacked, while the gel is setting. This is to maintain the structure of the gel forming during cooling and to keep purge to a minimum, which is especially important for products that are sliced and vacuum packed. Starch shows retrogradation in products that are cooled too slowly and there will be purge in the packed product (see Chapter 6, Section 6.2.2). Products should not be placed in a freezer to cool them quickly. The water in the outer layers of the product would turn into ice while the interior of the product would still be warm, and ice crystals in the outer layers would damage the gel. When the ice crystals melt, the damaged protein and gel matrix cannot reabsorb water well and WHC will fall, resulting in a large amount of purge. Products which are filled in waterproof casings and are not going to be sliced should be cooled and stored at 0–2 °C.

### 10.3.5 Slicing and shaving

The majority of highly extended added-brine ham is sold sliced and vacuum packed. Shaving is normally not possible because of the low meat content. High-quality added-brine ham products are sold sliced and vacuum packed, or shaved and modified atmosphere packed.

The product is cooled to between approximately –1 and 0 °C before

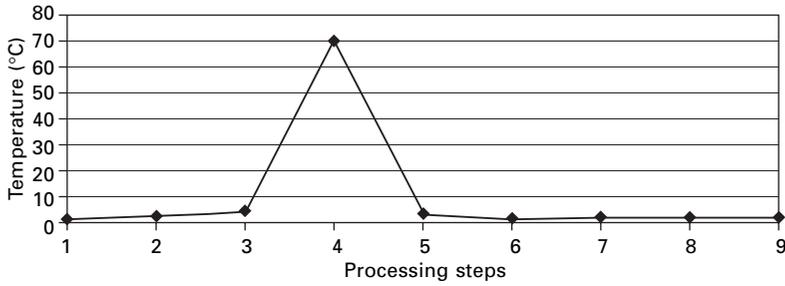
slicing, so that it can be sliced easily in a high-speed slicing machine. Condensation must be avoided during slicing or shaving (see Chapter 4, Section 4.12 ) because it reduces the shelf life of the product by encouraging the growth of bacteria. Hygiene requirements for both equipment and personnel are extremely high, because any form of recontamination during slicing or shaving of the product will significantly reduce shelf life. Added-brine ham is also sliced into slices of around 8–10 mm thickness and sold as ham steak in many countries.

### 10.3.6 Packaging and storage

Sliced products are commonly vacuum packed in either a stack or a shingle arrangement. The vacuum must be at least  $-0.98$  bar and the bags have to be properly sealed. Care should be taken to make sure that none of the product is trapped in the sealing line, as this will prevent a complete seal. The same applies if thermoforming packaging machines are used. The vacuum bags should be impermeable to oxygen to prevent the growth of aerobic spoilage bacteria such as *Pseudomonas* spp. Sliced products can also be packed in vacuum-shrink bags and then submerged for 1–2 s in water at 90 °C. This post-pasteurization is more effective for products packed in a shingle arrangement than for stacked products, because a larger surface area is exposed to the hot water and so more bacteria are killed. However, this process does not compensate for poor hygiene during slicing because the inner surfaces of the slices are not exposed to the high temperatures.

Sliced vacuum-packed added-brine hams often have purge inside the bag. Purge results from insufficient binding within the product, which may simply be due to insufficient levels of protein and functional additives in these highly extended products. Purge can also result from poor heat treatment, because carrageenan and starch are only fully functional at around 70 °C. Purge often contains a milky substance, primarily signifying the presence of high numbers of heterofermentative *Lactobacillus* spp. Milky purge has a low pH and is microbiologically stable, but is not acceptable to the consumer.

The gas mix for modified-atmosphere packing is usually 30–50% carbon dioxide (CO<sub>2</sub>) and 50–70% nitrogen (N<sub>2</sub>), with 30% CO<sub>2</sub> and 70% N<sub>2</sub> most often being used. CO<sub>2</sub> improves shelf-life because carbonic acid forms on the surface of the sliced product (CO<sub>2</sub> + H<sub>2</sub>O → H<sub>2</sub>CO<sub>3</sub>). Carbonic acid is a weak acid but sufficient to inhibit bacteria. CO<sub>2</sub> levels above 60% lead to the formation of excess carbonic acid, which may make the product taste sour. Because CO<sub>2</sub> is highly soluble under cold conditions, high CO<sub>2</sub> levels in a modified-atmosphere-packed product make it appear vacuum packed (a pseudovacuum). The level of oxygen (O<sub>2</sub>) in the modified atmosphere should be less than 0.8%, with levels below 0.5% being optimal. O<sub>2</sub> speeds up discolouration and shortens shelf life. N<sub>2</sub> is an inert gas and so does not react with anything in the product; therefore it replaces O<sub>2</sub> in the packaging.



**Fig. 10.1** Temperature changes during the processing of brine-added ham (see text for the description of steps 1–9)

With all methods, the top of the packaging is usually printed with branding and nutritional information, and often a picture of the product itself. This not only makes the product attractive to the consumer but also protects the contents from exposure to light and hence prevents the curing colour from fading. Under prolonged exposure to light, photolysis occurs and NO separates from myoglobin, which results in the formation of metmyochromogen, thus causing greying and colour fading.

The packed products are stored at between  $-1$  and  $2$  °C, which drastically inhibits the growth of most bacteria. Bacterial spores cannot germinate at such low temperatures and all, or most, vegetative pathogens have already been killed during thermal processing. A storage temperature of  $4$  °C is theoretically still safe from a microbiological point of view, but every single degree below  $4$  °C extends the shelf life many times over.

Figure 10.1 illustrates the temperature regime in added-brine hams during different processing steps: step 1, mixing commences; step 2, mixing is completed; step 3, ham is filled; step 4, cooking; step 5, cooling; step 6, slicing and packing; step 7, Storage; step 8, Transport and distribution; step 9, Storage at shop level.

## 10.4 Summary of critical production issues

- 1 The temperature of the meat to be processed should not be above  $4$  °C.
- 2 No frozen meat should be used.
- 3 The meat should have a low bacteria count, between  $10^2$ – $10^4$  per gram of meat.
- 4 The composition of the brine should be calculated on the basis of the expected level of extension and cooking yield.
- 5 Additives should be added to the brine in the correct sequence.
- 6 The temperature of the finished brine should be between  $-1$  and  $2$  °C.
- 7 Mixing under strong vacuum is best for effective protein activation, colour development and avoiding foam formation.

- 8 The ham mass should be filled under vacuum tightly into the desired casings, netting or mould to avoid air pockets.
- 9 The product should be cooked at 76–80 °C until a core temperature of 70–72 °C or the equivalent  $F_{70}$  value is reached.
- 10 The product should be cooled quickly to a temperature below 10 °C and then to below 4 °C but should not be cooled by placing it in a freezer.
- 11 Slicing or shaving must be carried out under cold and strictly hygienic conditions to avoid the formation of condensation.
- 12 The product should be packing under an appropriate vacuum or modified atmosphere.
- 13 The product should be stored at between –1 and 2 °C.

# 11

## Typical re-formed products from around the world using non-injection methods for adding brine

### 11.1 Sandwich ham (Australia)

Sandwich ham in Australia is a medium-quality added-brine ham and is made from minced-pork trimmings. The trimmings used are 85–90 CL. The meat is minced with a 3–6 mm blade, and the level of extension varies between 60% and 100%. The type and amount of additives used depend on the level of extension required.

Table 11.1 illustrates two examples of additives with respect to the total mass (meat and brine) based on 60% and 100% extension, resulting in 160% and 200% final yields. For example, to obtain 60% extension, 60 l of brine would be added to 100 kg of meat, resulting in a total mass of 160 kg. The 60 l of brine would contain 0.8 kg of phosphates, 0.48 kg of carrageenan, 0.8 kg of soy isolate, 3.2 kg of salt, 32 g of nitrite, 80 g of ascorbate and 4.8 kg of starch. The amounts of additives are calculated using the total mass (160 kg) and the amount of additive required per kilogram of total mass. The remaining amount up to 60 kg is iced water and so, in this example, 49.8 kg.

The brine is added to the minced meat and the mixture is normally mixed in a paddle mixer, rather than being tumbled. A full vacuum is applied during mixing, and the process takes around 3–4 h before the mixture is placed in a chiller overnight. The next day, the mass is mixed again for around 1–2 h, and then filled into waterproof casings. The slightly underfilled product is placed in square (4 in × 4 in) grid moulds. The ham mass extends into the corners of the mould during thermal treatment, resulting in a square end product. The meat is cooked with steam or in a water bath at around 76–80 °C until a core temperature of 70 °C is reached. The finished product is

**Table 11.1** Use of additives in 60% and 100% added-brine hams

	Amount (g per kg of total mass) for the following levels of extension	
	60%	100%
Ham phosphates	5	5
Carrageenan	2–3	3–4
Soy protein	3–5	10–15
Salt	20–24	20–24
Nitrite	0.18–0.25*	0.18–0.25
Ascorbate	0.5–0.7	0.5–0.7
Fermented rice	0.05†	0.15
Starch	20–30	50–70
Flavour	1–5‡	1–5

\*The values shown represent 180–250 ppm of nitrite applied to the raw uncooked product per kilogram of total mass.

†The amount of fermented rice added can vary significantly depending on the type of fermented rice used; other colours, such as carmine, are also used.

‡The level of flavouring added varies depending on the type of flavouring chosen.

predominantly sold in whole pieces to sandwich bars, or sliced and vacuum packed.

## 11.2 Chicken loaf

Chicken loaf is produced worldwide and there are a huge variety of products sold under this name. A high-quality chicken loaf is made from chicken breast meat at 30–50% extension, and the finished product is white in colour. Commonly, no nitrite is added to such ‘white’ products. The breast meat is minced with a kidney or 20 mm blade so that large pieces of meat are visible in the finished product. The amount and type of additives used for high-quality chicken loaf vary greatly but, in most cases, phosphate, carrageenan and some starch is used. Proteins are not normally added at this extension level unless food laws dictate a certain level of protein in the finished product. Around 4–5 g of phosphates per kilogram of total mass are added, and 2–5 g of carrageenan per kilogram of total mass, depending on the desired level of extension. Products that are extended around 50% normally require 10–30 g of starch per kilogram of total mass to prevent water separation if a waterproof casing is used. Starch and whey protein lighten the colour of the product and whey protein complements the flavour of chicken meat well. Smoke flavouring can also be added.

To produce a chicken loaf with 50% extension using coarse-minced chicken breast meat, phosphates are added at 4–5 g per kilogram of total mass, carrageenan at 2–3 g per kilogram of total mass, whey protein at 5–10 g per

kilogram of total mass and starch at around 30–40 g per kilogram of total mass. Whey protein matches the flavour of meat well and also lightens the colour of the product. Salt is added at about 14–18 g per kilogram of total mass and nitrite is most often not introduced into these ‘white’ products. Quite often, mixed herbs or other visible spices are added to the ham mass to make the finished product more attractive.

High-quality chicken loaf is also sometimes tumbled instead of being mixed. Tumbling lasts for around 3000–5000 rev, depending on the level of extension and the type of baffles inside the tumbler. Baffles need to be gentle for chicken meat because it is soft. Waterproof casings are most common, but fibrous casings can also be used for chicken loaf. Products in waterproof casings are cooked with steam or in a hot-water bath at 76–80 °C until a core temperature of 70–72 °C, or the desired  $F_{70}$  value, is reached. Fibrous casings may have a layer of smoke on the inside (see Chapter 35, Section 35.5). Products in fibrous casings are dried at 60–65 °C for 30–60 min, smoked at 65–70 °C until the desired smoke colour is obtained and finally cooked in steam or a water bath at 76–80 °C until a core temperature of 70–72 °C is reached. Drying and smoking add a distinctive appearance and taste to chicken loaf.

An ‘economy’ chicken loaf typically uses chicken MDM, chicken skin emulsion and some thigh or breast meat as the raw materials. Products containing no breast meat are also common where customers cannot afford a high-quality product. In extreme cases, chicken loaf is made predominantly from chicken MDM and chicken skin emulsion, and hardly any real meat is used. This mix of MDM and skin emulsion is extended by 80–100% and functional additives such as carrageenan and starch stabilize all the water added. The amount of protein added, mostly soy protein, is high, helping the texture of such low-meat products. The amount and type of additives used for economy chicken loaf vary greatly and countless different combinations are possible. In general, the amount of salt is 16–20 g per kilogram of finished product, carrageenan 5–7 g per kilogram of finished product, soy protein 20–40 g per kilogram of finished product and starch 40–120 g per kilogram of finished product. A compromise has to be reached between obtaining the maximum yield and avoiding water separation during cooking on the one hand, and the cost of all the additives on the other hand. Nitrite is occasionally introduced in economy chicken products.

The processing technology for economy chicken loaf is different from that used for the higher-quality chicken loaf in that sometimes the MDM, chicken skin emulsion and around 30% of the total brine are mixed together in a bowl cutter at slow knife speed to eliminate all possible lumps of MDM and skin emulsion. This slurry is then added to the mixer with the other minced meat and remaining brine and mixed. The mixture is then filled in waterproof casings and cooked at 76–80 °C until a core temperature of 70–72 °C is reached. In extreme cases, all the raw materials are placed in the bowl cutter and all the brine is added while cutting the entire mass at a slow

knife speed. None of the meat materials are minced in advance and all comminution takes place in the cutter. This eliminates the processing step of mincing and results in 2–3 mm meat particles. Once all the brine is added to the materials present in the cutter and the desired degree of comminution is reached, the total mass is removed and placed in a mixer. Mixing takes place under vacuum and is followed by filling, cooking, cooling and packing. A third method is to add all the brine in the bowl cutter and to cut the meat materials and brine at a medium–fast speed until a fine paste is obtained. This paste is not mixed but filled directly into the casings and cooked. Products made this way are commonly of very economical quality and no meat particles are visible in the finished product. The high degree of comminution activates a fair amount of protein and nitrite becomes evenly distributed during cutting. Most of the binding in such highly extended products is achieved by additives and not by the meat itself, as such products commonly contain less than 30% meat. Chicken loaf in Australia is generally made from chicken breast as well as a small amount of thigh meat, extended between 40% and 60% and is sold in whole pieces to delicatessen shops for sandwiches or sliced and vacuum packed. High-quality products, made from chicken breast meat only, extended between 25% and 40%, shaved and modified atmosphere packed are becoming more common.

### **11.3 Delicates ham (Austria)**

Delicates ham is a perfect example of a high-quality added-brine ham. Lean pork meat, leg and loin, is membrane skinned and all visible fat is removed. The layer of connective tissue on the back of the loin is also removed; so the meat is completely free of any sinew and fat. Sow meat is often used as it has a strong red colour, is low in intramuscular fat and is less expensive than pork from young pigs.

The meat is passed through the mincer worm once or twice, which tears the muscle apart nicely and creates a large surface area. The level of extension is around 25–30% and additives such as phosphates (4–5 g per kilogram of product), salt (16–20 g per kilogram of product), nitrite (around 250 ppm per kilogram of product of the raw uncooked mass), ascorbate (0.5–0.7 g per kilogram of product) and sometimes a touch of carrageenan (1–2 g per kilogram of product) are used. Various flavourings such as garlic and juniper are commonly used as well. The brine is added to the meat in the tumbler and the mixture is tumbled for around 3000–3500 rev under full vacuum. The tumbled mass is primarily filled into fibrous casings, but waterproof casings are sometimes used as well. Products in waterproof casings are thermally treated with steam or in a hot-water bath at 76–80 °C until a core temperature of around 70 °C is reached. Products in fibrous casings are generally dried first at 60–65 °C for around 30–60 min, until the surface of the casing is dry, then smoked at 65–70 °C for around 1 h before being finally cooked with

steam at 76–80 °C until a core temperature of 70 °C is reached. Cooking can also be carried out in dry heat, and this increases the intensity of the colour and flavour.

Spices and herbs that remain visible in the finished product are frequently added to this type of ham. Care should be taken if green peppercorns are used, as these are generally sold in brine and the extra brine, which is acidic and extremely salty, must not be added to the ham mass. Green peppercorns are therefore rinsed well with water and drained before being added.

# 12

## Cooked sausages

Cooked sausages are an important meat product and exist in two forms. One consists of a homogeneous fine mass with no visible particles of meat or fat, while the other has a fine homogeneous mass as the base but also has visible particles of fat and meat. Well-known products such as frankfurters, Vienna sausage, hot dog, beer ham, meat loaf and many others are eaten daily all over the world. Any type of meat can be used to make cooked sausages, including exotic meats such as crocodile and kangaroo. Cooked sausages are commonly sold as portioned products, such as hot dogs, and are consumed either hot or cold, or sliced.

A cooked sausage is a complex mix of different systems, including solutions of dissolved materials such as protein and salts, suspensions of larger particles in added water, gels made from muscular proteins, and emulsions that contain stabilized fat in a gel made from protein and fat which is partially present in liquid form.

The most significant difference between cooked sausages and cooked hams is the presence of fat in the product. The major aim during the manufacture of cooked sausages is to emulsify added fat and to bind, or immobilize, added water with activated protein. The impact of mechanical energy from cutting and shearing forces destroys the sarcolemma, and additives such as phosphates and salt activate the released protein. The activated and solubilized protein not only immobilizes the added water but also emulsifies and covers the added fat, stabilizing both added water and fat in a three-dimensional matrix.

The quality of cooked sausage varies considerably all over the world. Frankfurters or Vienna sausages made in Germany and Austria contain a fair amount of good-quality meat and fat, and generally no non-meat materials,

such as soy protein. Frankfurters produced in South Africa or the Philippines sometimes do not contain any 'real' meat at all, and the entire recipe is made from MDM meat, fat and skin emulsions, and up to 15% of non-meat ingredients such as soy protein and starch.

The term 'emulsion' is used universally for a finely cut sausage with no visible fat, although this is technologically incorrect. The term 'emulsion' is only justified if the fat material processed is liquid, e.g. oil, because only then are the water and fat present in their liquid form within the raw uncooked product. The solubilized, or activated, protein acts as the emulsifier between these normally non-mixable materials, resulting in a fat-in-water emulsion. Other added proteins such as soy also act as emulsifiers. A cooked sausage containing solid fat, for instance from pork or beef, largely resembles a suspension where the finely chopped fat phase is distributed in the liquid water phase, and such a cooked sausage is therefore a fat-in-water product. Most of the fat in such a system is present as finely cut solid fat, although the temperature rise where the knives in the bowl cutter come into contact with the meat liquefies some of the fat, resulting in a small amount of emulsion present in the suspension.

## 12.1 Selection of raw materials

Most customers buying a cooked sausage desire a firm product with good bite, firm texture and a strong red curing colour. Generally, higher proportions of lean meat in the product contribute positively towards a firmer bite and texture as well as a stronger curing colour. Unfortunately, lean meat is by far the most expensive component in a cooked sausage and economic reasons often determine the amount of lean meat in a recipe.

As in all other meat products, the microbe count of the meat and fat material to be processed should be as low as possible. Fat is often neglected, but fat with a high microbe count affects rancidity, flavour, shelf life and colour stability in the finished product. The number of bacteria on meat used for cooked sausages should be between  $10^2$  and  $10^4$  per gram of product and a pH between 5.7 and 6.0 is preferred. Solubility is enhanced in this pH range because some maturation will already have taken place, reducing the number of cross-links between actin and myosin. The WHC of the proteins is also improved.

The temperature of meat and fat materials to be processed depends on how they will be processed. If fresh chilled meat and fat is processed, the temperature should be between 0 and 4 °C. Low temperatures delay bacterial growth and optimize solubility of the main myofibrillar proteins, myosin and actin. Salt-soluble proteins, such as myosin and actin, have a 300% stronger WBC and ability to emulsify fat than water-soluble proteins, such as sarcoplasmic proteins. Water is ultimately bound on to the side chains of polypeptides, and ionized amino acids can immobilize 5–6 mol of water per

amino acid, whereas non-ionized amino acids can hold around 3 mol of water per amino acid and non-polar amino acids can hold up to 1 mol of water per amino acid. Myosin, actin and partly tropomyosin are responsible for binding water in muscular protein.

The lean meat in a sausage affects the immobilization of added water, the emulsification of fat, and the texture, bite, colour and taste of the product. Exchanging one type of meat for another, even if they have the same CL grade, results in a different product. For example, if beef is replaced by pork, the firmness and bite of the finished product will be reduced. However, if a smoother texture is wanted then replacing some beef with pork is of benefit. Meat and fat trimmings should be purchased based on CL grades rather than VL grades, because the VL grade as labelled frequently does not correspond to the actual content, and often the meat is more fatty than expected from its VL grade. Meat and fat can only be stored for a prolonged period of time if they are frozen, as bacterial growth is stopped at temperatures around  $-20\text{ }^{\circ}\text{C}$ . However, enzymatic processes, such as those that cause rancidity, still continue at very low temperatures; so the length of time that meat and fat materials can be stored is largely determined by the fat content. If frozen meat is thawed before being processed, then ice should be added to keep the temperature low during the cutting process. Frozen and semifrozen (tempered) materials are commonly processed because significantly less ice has to be used. Adding water instead of ice is more economical and also gentler on the knives of the bowl cutter. When fully frozen meat is processed, it is generally flaked or minced before being placed in the bowl cutter to prevent damage to the knives. Minced or flaked frozen meat and fat material is also commonly used in a mixer-emulsifier system, where water is added to the sausage mass during mixing. Fat can be processed chilled but is mostly processed frozen. The advantages of using semifrozen or frozen materials will be explained in Section 12.5.

PSE meat is not suitable for cooked sausages because it has a reduced native protein content. This means that its WHC as well as the ability to emulsify fat is reduced (see Chapter 4, Section 4.1) because activated protein is necessary for those processes. PSE meat is also pale in colour, which is not beneficial for cooked sausage products, and practical experience shows that PSE meat is frequently a problem if small batches, or quantities, are made at any given time. When a high proportion of pork meat is used in a single batch, and most of the pork comes from a single pig which gave PSE meat, the final product will have a poor colour and poor firmness. Fat and water separation also occur occasionally when the level of native proteins is low, although the presence of PSE meat is generally not the only reason that separation occurs as the processing technology has a major impact on the stability of an emulsion as well.

Most batches of cooked sausage that contain a mix of pork meat from different animals, together with other meats such as beef and some PSE meat, do not cause any problem during processing. Experience shows that up

to 15% of the total amount of pork used in a batch can be PSE without causing a significant difference in the finished product. In a product where the total meat portion contains, for example, 90% beef and only 10% pork, then almost all of this pork could be PSE meat without having technological problems. Problems arise when a large amount of pork meat is used in the recipe and much of it is PSE. This is particularly significant in products that contain large pieces of show-meat. Show-meat is commonly extended by around 10–15% before being mixed with a fine emulsion. Water is sometimes released from show-meat during thermal processing, which leads to water separation in the final product.

Beef is commonly used in cooked sausages, and some DFD beef can be used (see Chapter 4, Section 4.1) without harming the finished product, although using large amounts of DFD beef should be avoided. Too much DFD beef can result in a poor curing colour and shorter shelf life because of its high pH. On the other hand, DFD meat shows excellent protein solubility and a high WHC, and therefore does not have a negative impact on the stability of the emulsion.

Companies that operate their own slaughterhouse use ‘bleeding meat’ in cooked sausages. This is the meat around the place where the animal was cut for bleeding and is almost always from the neck area, just below the head. Neck meat has a large amount of connective tissue, which in turn contains much collagen. Collagen turns into gelatin during cooking, which contributes to firmer texture and bite. The blood in this type of meat also leads to a stronger red colour in the finished product.

Meat from sows, or choppers (old female breeding pigs), is widely used in cooked sausages. Sow meat contains high levels of myoglobin owing to the age of the animal and, once in contact with nitrite, contributes to a strong curing colour. The water content in muscle tissue of older animals is lower than that of a young pig (around 6 months), and therefore WHC is enhanced. Sow meat is also quite cheap in most countries.

Boar meat (old male breeding pig) generally has excellent WHC and is very lean, high in protein and at the same time very low in fat. The major disadvantage of boar meat is its smell. Certain hormones in boar meat, mainly androstenone and testosterone as well as scatol, cause a urine-like smell, which is not acceptable to most consumers. To remove the smell, the boar is castrated several months before slaughter, once it is no longer contributing to breeding. The urine-like smell disappears during the time between castration and slaughter, making boar meat useable for sausages. However, a castrated boar is not useful to the farmer and is expensive to feed. When meat from non-castrated boars is used, it should not total more than 5–10% of the meat used, and extra spices should be added to hide the smell.

In most cases, cooked sausages are made from a mixture of beef, pork and other meats. Pork is good for an elastic and smooth texture, but does not enhance firmness, whereas beef adds texture and firmness, as well as promoting a strong curing colour. Although a mixture of pork and beef results in an

excellent finished product, it is not always possible to use both types of meat, mainly for religious reasons.

MDM, or MSM (see Chapter 4, Section 4.2), is widely used for cooked sausages, and low-cost products generally contain a high amount of MDM. Soft MDM contains around 14–17% protein, and its WHC and ability to emulsify fat is around 25–35% less than lean muscle meat. Hard MDM only contains around 12–14% protein, and its ability to immobilize water and to emulsify fat is only around half that of lean muscle tissue. Hard MDM does not contribute much to texture and firmness and can cause production problems because the levels of fat vary greatly, especially in chicken or turkey MDM. MDM meat used for making cooked sausages should have a low bacteria count, must not be rancid (especially important for chicken or turkey MDM) and should contain very few bone particles. Products containing high levels of hard MDM can turn dark during thermal treatment and the introduction of calcium caseinate helps to correct this occasional form of discolouration.

Another type of MDM meat is produced from the entire carcasses of hens, rather than using the carcasses of young chickens that have had the valuable parts such as breast, legs and wings removed. Such whole-carcass MDM has significantly better functional properties than traditional hard MDM because of the higher levels of protein, lower levels of fat and coarser meat particles.

The texture of cooked sausages made using large amounts of hard MDM has to be built up by adding materials such as strong gelling soy protein, skin emulsions and starch. All these add firmness and body to an economy-quality cooked sausage and the level of added water is low at the same time (around 10–15% only). Chicken sausages should be pale coloured or white, and the majority of meat processed should be chicken breast. When breast meat is too expensive, some thigh meat can be used, and the finished product then whitened by the addition of chicken skin emulsion. Adding 2–3% starch, or more, also helps to lighten the colour. Chicken thigh meat contains some collagen, which contributes to firmness. Light-coloured sausages can also be produced from veal meat, because it is very young and thus the amount of myoglobin present in the muscle tissue is small.

Rework is generally material which has been fully cooked already that cannot be sold. The reasons for obtaining rework include splitting during cooking and incorrect amounts of spices, among others. Cooked products have no functionality regarding binding of water or emulsifying fat if reworked; they act as a non-functional filler. Thus the amount of rework added to a freshly produced batch of cooked sausages should be as little as possible and not exceed 1–4% of the total batch weight. The activated protein from the new batch of sausage has to immobilize the rework, or non-functional filler, and therefore the stability of the emulsion, firmness and texture of the new product is reduced.

In extreme cases, high levels of rework in a batch of sausage can cause the emulsion to break, resulting in fat and/or water separation. In order to keep

the amount of rework as low as possible, care must be taken during the various processing steps so that each batch consists of as much high-quality or saleable product as possible. Rework should be free of any casing, especially if plastic casings were used, as well as clips, netting or any other packaging material. If coloured casings were used in the product to be reworked, the new product may have coloured dots. Rework should be used as quickly as possible and should have a low bacteria count. Unfortunately, rework is very often not used quickly, and the material becomes slimy and sour. It is quite common for rework in this state to be washed with warm water before use, which improves the microbiological status a little but rework should never be allowed to get to a state when it shows slime or sourness. If there is much rework, this means that materials are handled twice, which is inefficient and makes the material cost for using rework extremely high. Rework is also a major problem for quality control procedures, because materials from one batch are introduced into other batches, affecting traceability.

### **12.1.1 Use of hot-boned meat (warm-meat effect)**

Warm, or hot-boned, meat is very useful for producing cooked sausages with no added phosphates, and beef is occasionally prepared this way. The WME can be preserved in two ways (see Chapter 4, Section 4.3) and meat that has been frozen before the onset of rigor mortis contains the proteins actin and myosin in a separate, and therefore highly soluble, state. The pH for meat where the WME has been preserved via fast freezing is around 7.0–7.2 and, as this is far from the IEP, the WHC is very good as well. However, the non-acidification of this type of meat means that it loses some of the normal, slightly bitter meat taste. Meat that has undergone rigor mortis completely has a pH of around 5.4, and the actin and myosin are bound together in an actomyosin complex. WHC is poor owing to the low pH, and additives such as phosphates and salt must be used to separate actin and myosin and to make the protein fibres soluble (see Chapter 8, Section 8.2.1).

Hot-boned meat that was frozen using nitrogen (N<sub>2</sub>) or carbon dioxide (CO<sub>2</sub>) must not be fully thawed before processing because rigor mortis would take place very quickly during thawing (in the bowl cutter). Actin and myosin would therefore link together and all the advantages of hot-boned meat, or the WME, would be lost. When frozen or tempered hot-boned meat is processed, salt and ice, and/or water, is added to the bowl cutter during cutting, because it solubilizes the proteins by widening the gaps between actin and myosin as they thaw, thus preventing the actomyosin complex from forming. This phenomenon is known as thaw rigor (see Chapter 4, Section 4.4). Large amounts of protein are solubilized without the need to add phosphates. Hot-boned meat is generally used in cooked sausages, which are sold as ‘home made’, ‘healthy’ or ‘farmer’s’.

### 12.1.2 Fat

Fat stabilizes the solubilized protein gel network in a sausage and contributes to succulence and texture. Fat also helps to prevent shrinkage of the protein during cooking by acting as a filler. Pork fat is the most commonly used fat in cooked sausages. Fat from the loin, belly and neck is the most suitable fat for cooked sausages because of its low unsaturated fatty acid content. However, fat from loin or neck is often used for products such as salami as those products are generally sold at a higher price than cooked sausages. Fat from all the remaining parts of a pig such as shoulder and leg is frequently used for cooked sausages but the inclusion of loin or neck fat as well as bellies is of advantage. Shoulder or leg fat has a lower melting point than fat from the neck or loin and the risk of fat separation in the finished product is enhanced if the temperature during emulsification exceeds 16–18 °C. In practical terms, fat utilized is often a mixture from all parts of a pig carcass. The fat must not be rancid, it must be free of skin and it should have a low bacteria count:  $10^2$ – $10^4$  per gram of product is optimal. Quite often, fat is processed frozen, because this is the only way to store it for any length of time. This reduces the need for ice during processing because the frozen fat keeps the temperature low. Greater amounts of water can be used, which costs less and is less harmful to the bowl-cutter knives.

Where pork cannot be eaten, beef fat is used. It is commonly turned into a beef-fat emulsion first (see Section 12.3), to avoid the sandy and greasy mouth feel frequently present in cooked sausages containing beef fat, which is due to the low melting point and high saturated fatty acid content of beef fat. Beef trimmings of different CL grades are used in large-volume production of cooked sausages in many parts of the world and they contain a certain amount of fat. For example, beef of 85% CL grade contains 15% fat and 85% lean muscle tissue. A fat emulsion is not made in this instance, and the sandiness either is accepted by the customer or can be avoided, or reduced, by mixing in some pork.

Very economical sausages are often produced using fatty trimmings from beef and mutton (old sheep), both high in saturated fatty acids, without any added pork or prior preparation of a beef-fat emulsion. Here, the sandy and tacky mouth feel is accepted by the consumers simply because they cannot afford to pay a higher price for sausages and food in general. Fatty trimmings of beef or mutton are generally processed in a frozen or semifrozen state.

Jowls, or cheeks, are another excellent fat material for cooked sausages. Jowls contain around 30% lean muscle tissue as well as a fair amount of connective tissue. The connective tissue turns into gelatin during cooking and contributes to firmness and bite in the finished product. Jowls are quite often the main raw material for products such as frankfurters, together with some lean meat, beef or pork. Care must be taken to ensure that all glands are completely removed, because jowls are prone to containing pus and the glands frequently contain high numbers of *Staphylococcus aureus*. Another fat widely used in cooked sausages comes from fatty pork bellies, which

cannot be used for other meat products made from belly itself. Bellies from sows, or choppers, are used to provide fat for cooked sausages. Sow meat is generally less expensive than normal pork; the lean-meat portion has a high WHC and is dark in colour (owing to high levels of myoglobin) which, when it comes into contact with nitrite, contributes to a strong curing colour in the finished product.

### **12.1.3 Oil**

Vegetable oil is used when no solid fat is available. Cooked sausages produced with oil are lighter in colour than those made with solid fat. Oil is essentially 100% fat, while solid fat is only around 85% fat. Oil has a significantly larger surface area than finely cut fat and this makes the final colour lighter, which quite often gives the product a 'healthy' image. Cooked sausages made with oil are true emulsions, as both water and fat are present in liquid form, and activated, or solubilized, protein acts as the emulsifier. Oil must be chilled before use to keep the temperature of the total sausage mass low and therefore to allow enough time for the oil to be emulsified properly.

## **12.2 Production and use of pork and chicken skin emulsion in cooked sausages**

Pork or chicken skin contains around 55% water, 35% connective tissue (mostly collagen), around 5–10% fat and 0.5% ash. Emulsions made of chicken or pork skin are widely used in cooked sausage production as they are inexpensive and add bite and firmness. Tendons or ligaments are also used for the same reason, and all these raw materials are very high in connective tissue and therefore collagen. When heated, collagen turns into gelatin and so contributes to a firmer bite, snap and texture.

It is very important that the raw materials for skin emulsions are treated and stored properly to keep the bacteria count low. They can be frozen and then thawed before being processed into an emulsion. The term 'emulsion' is not fully correct in this instance as, firstly, no fat is added directly and, secondly, any fat present is in a solid, and not liquid, form.

Skin or tendon emulsions can be made in different ways and each method has advantages and disadvantages. The two main options are to make an emulsion with non-treated material, or to use material that has been treated before being turned into an emulsion. The raw untreated skin, primarily chicken skin for this method, is cut with water and soy protein generally in a ratio of 1:4:4, where 1 kg of soy protein (predominantly soy isolate) is cut with 4 kg of iced water and 4 kg of skin. The soy protein is cut with cold water for around 2–3 min until a gel-like material is obtained. Cutting takes place under the highest knife speed possible and the knives used should be

as sharp as possible. Chicken skin (mostly minced) is added to the bowl cutter and the total mass is cut at high speed until a finely cut mass is obtained with the maximum temperature being around 10–14 °C. Slightly frozen skin and some ice are used to prolong the cutting time, ensuring that a fine paste is obtained. The finely cut paste can be passed through an emulsifier afterwards to increase smoothness of the emulsion which is not often practised as cost is added to the material owing to the additional processing step. Salt (and nitrite) is used to extend the shelf life of the emulsion and is added at the end of the cutting process and mixed in gently. The shelf life of this type of emulsion is between 3 and 4 days stored at 0–3 °C. This is the simplest and quickest method of producing a skin emulsion, but all the water present is immobilized by added protein. The collagen present in the skin does not hold, or immobilize, any added water. Another method makes proper use of collagen to immobilize added water. By adding double-sour phosphates in conjunction with a small amount of soy protein, chicken and pork skin can be extended by around 80–90%. Thus 100 kg of skin can be turned into 180–190 kg of emulsion. Around 10 g per kilogram of total emulsion of sour phosphates and soy protein is added to the bowl cutter once cutting of the skin has started. Iced water, and some ice, is gradually added afterwards while cutting under a high speed. The principle behind this method is that the collagen starts to swell through the addition of sour phosphates and water is absorbed into the triple-helix structure as the result of swollen collagen (see Chapter 1, Section 1.3).

With this method, collagen immobilizes all the added water, and the small amount of soy protein is only added to emulsify the usually small amount of fat attached to the skin. This type of emulsion can also be passed through an emulsifier to obtain an even finer paste, and salt can be introduced at the end of the cutting process as well. This method uses well-chilled or even semifrozen skin to obtain a low temperature right from the beginning and the addition of iced water, or some ice, means that the cutting period can be longer. The amount of soy protein added to emulsify the fat connected to the skin (normally pork skin) is typically 0.5–2%, and is calculated according to the total mass (skin + water or ice).

The advantage of the above two methods is that the emulsion can be made directly without prior treatment of the materials and therefore labour costs are low. The disadvantage of these methods is that the final emulsion obtained is not as fine and creamy as that obtained from treated skin.

Chicken and pork skin can also be treated by placing them in a sour solution overnight. The soaking solution is prepared from a blend of different food acids and water, with the blend of food acids showing a pH of around 1.5–1.8. This liquid blend is mixed with cold water, with a 3% solution generally used for soaking chicken skin and a 5% soaking solution for pork skin. A stronger solution is required to treat pork skin because the collagen in pork skin has a higher number of cross-links than the collagen in chicken skin. This is largely because a pig is much older at slaughter than a chicken.

Pork skin from sows cannot be treated successfully because the extremely high number of cross-links in the collagen molecules prevents proper swelling during soaking.

During soaking, the collagen starts to swell and water is effectively bound in the swollen collagen. Soaking results in a soft texture, making the skin easy to cut and hence resulting in an extremely fine and creamy paste when passed through an emulsifier. After overnight soaking under chilled conditions, chicken skin can increase in weight by between 70% and 90% and pork skin frequently shows a gain in weight of between 50% and 70%. Pork skin from pigs which were flamed during the slaughtering process to burn off remaining hairs tends to take up less water during soaking, with the amount depending on the degree of burning. The skin is washed thoroughly afterwards with cold water to remove excess acid from the surface. The washed material is then drained and often placed on trays and put in a freezer to reduce the temperature. Once it is well chilled, or even slightly frozen, the skin is placed in the bowl cutter and cut under high speed. Around 1% of soy protein is added to emulsify any fat present. Ice may also be added during cutting to obtain an extension of around 90–100%, based on the weight of the untreated skin. As an example, if 100 kg of chicken skin gained 90 kg (90%) in weight during soaking, around 10 kg of ice can be added in the bowl cutter to obtain 200 kg of emulsion. For pork skin, a final extension of around 190% is the norm. Salt (around 1.5–2%) and nitrite can be gently mixed into the emulsion once cutting is finished. The final temperature of a skin emulsion produced in this way should not exceed 15 °C, and processing semifrozen material prolongs the cutting process. Nitrite is not added if the skin emulsion is going to be used in non-cured products. This type of emulsion can be stored for 3–4 days at 0–3 °C.

Skin emulsions can also be stored in the freezer, and the finished emulsion is placed in trays in layers not higher than 10 cm so that the temperature of the emulsion falls quickly. If the layers are any thicker, cooling takes much longer and there is a risk of bacterial growth. Frozen skin emulsion is placed in the chiller the night before use so that it is not too hard to process.

Another method of making pork skin emulsion is to cook the skin first and then to cut it with water and soy protein in a ratio of 1:4:4. This method is not sensible from a technological point because collagen is denatured on cooking and loses its ability to hold water and to form a gel. Precooking the skin also represents an additional manufacturing step, which involves time and energy.

Beef ligaments can also be turned into an emulsion and the procedure is the same as for pork skin, soaking the ligaments in a 5% solution. Once again, a low bacteria count is vital because the water content of the final emulsion is extremely high. When no bowl cutter is available, the soaked, washed, drained and semifrozen materials can be minced with a small blade and placed into a paddle mixer. Around 1% of soy and around 1.5–2% of salt protein is added and the materials mixed well before being passed through an emulsifier once or even twice, to obtain a fine and creamy paste.

Other materials rich in collagen, such as the material obtained after putting lean meat through a separation machine to obtain soft MDM (see Chapter 4, Section 4.2), can also be turned into an emulsion. The collagen material obtained from the production of soft MDM, or by using a separation device during mincing, generally has a certain percentage of lean muscle tissue. Such collagen-rich material can be cut in the bowl cutter and around 20–30% of ice can be added. Additives such as phosphates are introduced at around 3 g per kilogram of total mass, and salt at around 18–20 g per kilogram of total mass. The term ‘total mass’ refers to the collagen-rich material and the ice together. By processing material obtained from soft MDM, well-chilled collagen-rich material plus 50–70% of the total ice and all phosphate and salt are cut at high knife speed for a while. The remaining ice is added once the temperature of the mixture reaches around 4–6 °C, which reduces the temperature back to around 0 °C. Cutting at a high speed continues until the temperature increases back to 12–14 °C. This produces a fine paste, which can be used for all types of emulsified sausage. A similar emulsion can be obtained by cutting the mixture until the temperature reaches around 6–8 °C in the bowl cutter and then passing it through an emulsifier.

### **12.3 Production and use of fat emulsion in cooked sausages**

Another source of fat is a fat emulsion. Fat emulsions are generally made from protein, low-value fat and water, with soy isolate being the protein most commonly used. Low-value fats include lard and kidney fat from pigs and cattle, beef suet and chicken fat. In most cases, these types of fat are disposed of, and sometimes the disposal has to be paid for. If added directly to a sausage emulsion, these fats cause a smeary, greasy and tacky mouth feel, and sausages containing a large amount of these fats can leave a thin layer of fat sticking to the gums in the mouth. Beef fat also results in a rough or sandy mouth feel if added directly to the sausage mass. Low-value fats have a large number of saturated fatty acids and are therefore quite hard, which makes them difficult to emulsify. To counteract the disadvantages and still to use inexpensive fats, a fat emulsion is produced and then incorporated into the sausage mass. The emulsion stabilizes the fat and reduces the sandy texture in the finished product.

The fat used for fat emulsions must not be rancid and must have a low bacteria count. These fats are commonly not treated or chilled properly and often have a high bacteria count but, even though they are low value, they should be treated like high-quality meat from a microbiological point of view. Fat emulsions made from rancid, smelly or slimy fat have a very negative effect on shelf life and flavour.

Fat emulsions are a very economical raw material and can reduce the cost of a recipe substantially. Experience shows that up to 25–30% of the total amount of pork fat in a recipe can be replaced with a beef or pork fat

emulsion with no significant difference in the finished product. Replacing high-value fat with a fat emulsion can be financially very rewarding, especially if large volumes of cooked sausages are produced every single day. Another way of using a fat emulsion is not to replace fat in the recipe, but to add an extra 2–3% to the recipe. If fat emulsion is added to every batch, the finished product does not change and the added fat is already stabilized so that it does not reduce the stability of the sausage mass significantly.

Fat emulsions are generally produced in a ratio of 1:5:5, with one part of soy isolate being cut with five parts of water and five parts of fat. Fat emulsions can be produced by hot or cold methods.

For the hot method, the fat is placed in the cutter and soy protein is added during cutting at high speed. After cutting for 2–3 min, hot water (90–95 °C) is added gradually, and the mixture is then cut until a fine creamy paste is obtained. Once fully emulsified, salt and nitrite can be gently mixed in to extend shelf life and to increase the microbiological stability. The finished emulsion is placed in trays in layers around 10 cm high and quickly cooled to below 5 °C to avoid bacterial growth.

The cold method starts by cutting water with soy until a shiny paste is obtained. This process lasts for around 3–4 min and must be completed properly to make sure that the soy protein is fully hydrated, otherwise it cannot act as an emulsifier. Once a shiny gel is obtained, which is also free of any lumps, fat (possibly minced) is added and the mixture is cut under a high speed until a stable emulsion is obtained. The maximum temperature once the emulsion is finished should not exceed 15–18 °C. The cold method uses only four parts of cold water for the actual process of cutting. Once a stable and finely cut emulsion is obtained, one part of ice is added to reduce the temperature of the total mass. Salt and nitrite can be mixed in gently once the emulsion is finished. Placing the emulsion in shallow trays and storing under chilled conditions, 0–3 °C, completes the process. The shelf life of a fat emulsion under chilled conditions is between 3 and 5 days, depending on the original bacteria count of the fat and storage temperature. Using raw materials with a low bacteria count and storing the emulsion at 0 °C is optimal. Emulsions made by the hot method have a slightly higher stability than emulsions made by the cold method. However, handling hot water in normally cold-processing rooms can be a problem, and some of the fat flavour is lost owing to the impact of hot water. Chicken fat emulsions are generally made using the cold method.

Fat emulsions are occasionally produced using caseinate, as they are slightly more stable than fat emulsions made with soy and the ratio of caseinate to water and fat is as high as 1:7:7. Caseinate is particularly useful for fat emulsions for products that are retorted at the end of processing. Fat emulsions produced with caseinate using the hot method are even more stable than those made using the cold method.

The water bound in a fat emulsion is not available for recipe purposes and sufficient water must be introduced in the overall recipe to activate the

protein sufficiently. Fat emulsion can also be produced with oil, usually in the ratio of 1:4:5. Thus 1 part of soy isolate is processed with 4 parts of oil and 5 parts of water, because oil represents 100% fat. Fat emulsions with oil are made using the cold method, and stabilizing oil first in an emulsion reduces the risk of fat separation in products made using oil, especially if the content of meat (protein) in the product is low.

## 12.4 Selection of additives

Phosphates (see Chapter 5, Section 5.1) are the most efficient additive for solubilizing muscular protein, and generally 3–5 g of phosphate are used per kilogram of total mass. Total mass includes all lean meat, fat, water or ice, other emulsions as well as all additives and binders. Therefore, 300–500 g of phosphate will be added for 100 kg of total mass. Most countries permit 0.5%, or 5 g, of phosphorus pentoxide ( $P_2O_5$ ) per kilogram of product, which represents around 8 g of phosphate added per kilogram of total mass. Such high levels of added phosphate do not result in increased functionality and 6 g of phosphate per kilogram of product can be seen as the absolute maximum level from a technological viewpoint. Special blends of phosphate, primarily containing diphosphates, are available for emulsified sausages and act quickly on protein during chopping or mixing—emulsifying. This is important because it takes only around 7–12 min to make an emulsion, and the protein must be activated first to emulsify fat and water in a secondary process. Phosphates are always added at the beginning of the cutting process, so that they can act on the protein right from the start.

Salt is the oldest additive and acts synergistically with phosphates (see Chapter 8, Section 8.2.1). Salt is added at the beginning of the comminution process. The amount of salt in cooked sausages varies considerably but should be above 12 g per kilogram of total mass in order to activate protein effectively. Optimal solubilization of protein from a technological standpoint occurs at around 5%, or 50 g, of salt introduced per kilogram of sausage mass, but this is not acceptable from an organoleptic point of view. Most cooked sausages contain between 14 and 18 g of salt per kilogram of total mass and local eating habits primarily determine the level of salt accepted by the consumer.

There is no legal limit on the amount of salt that can be added to meat products except for those described as ‘low sodium’. Potassium chloride is used instead of sodium chloride in low-sodium products to ensure the proper activation of muscular protein. The problem with potassium chloride is that most people start to detect a slight bitter taste at a level of around 3–4 g of added potassium chloride per kilogram of sausage.

In most low-sodium products, depending on the respective food standards in place, salt as sodium chloride can only be applied in tiny amounts, around 2–3 g per kilogram of sausage, because sodium is also commonly introduced

in the form of sodium phosphates, sodium nitrite, sodium ascorbate or sodium erythorbate. If 4 g of potassium chloride are added per kilogram of sausage in conjunction with around 3 g of sodium chloride, only 7 or 8 g of salt are present per kilogram of sausage, which does not activate protein effectively. Protein activation only becomes efficient at around 12 g of total salt added; so 8–12 g of potassium chloride are added per kilogram of sausage so that the total salt concentration, in conjunction with some sodium chloride, is at least 12 g per kilogram of sausage. The possible bitter taste due to such high levels of potassium chloride in the finished product can be masked to a large extent by adding sugar and extra spices.

Salt is also added at the beginning of the cutting process, together with phosphates, because this raises the ionic strength to its maximum level and promotes the solubilization of muscular protein. Salt-soluble proteins, such as actin and myosin, have better emulsification abilities than water-soluble proteins because of the presence of hydrophilic as well as lipophilic groups. Solubilized myosin mainly emulsifies fat, while activated actin immobilizes water strongly. However, solubilized myosin and actin should be viewed as working strongly in synergy, rather than separately. A denatured gel made out of solubilized actin and myosin creates a three-dimensional matrix and finely cut particles of fat are covered by a layer of protein. This layer of protein also prevents the unification of fat particles during cooking and therefore prevents fat separation.

Water or ice as such is not an additive, but it fulfils major technological functions in the production of cooked sausages for several reasons. Firstly, water is required to activate, or solubilize, muscular protein. Without water, little or no protein can be activated, and high levels of activated protein are required for a firm texture, the proper immobilization of added water and the emulsification of added fat. Secondly, ice is commonly used to counteract the heating effects of the high cutting and shearing forces generated by the knives on the bowl cutter. Where cutter knives turn at 3000–5000 rev/min, temperatures can reach 120 °C in certain areas on the knives, and so ice is essential to keep the temperature of the sausage mass down. Without ice, the temperature of the sausage mass would rise very quickly, shortening the time available for cutting and hence making it difficult to obtain a homogeneous emulsion without any visible fat particles and to activate the maximum amount of protein.

Added water also increases the succulence of the products and, finally, is still (in most countries) the most economical material used in the production of cooked sausages and other meat products. Ice must be made from water of drinking quality.

There is a huge difference between the cooling capacity of freshly produced ice (flakes or cubes) and that of ice which is several hours old and has been stored in the ice-making machine. Excess ice stored in the freezer at around –18 °C shows different cooling properties again. Ice that has been stored in the ice-making machine for hours and at a temperature of, say, between –2

and  $-5\text{ }^{\circ}\text{C}$ , is visibly still ice but has a vastly different cooling capacity from freshly produced ice, which is much colder. If the cutting procedure for a batch of sausage is fully standardized, significant differences in ice temperatures result in different finished products. If the standardized process is based on obtaining a certain final temperature of the sausage mass after emulsification, ice at a lower temperature prolongs the cutting process while ice at higher temperatures shortens the cutting process. Another consideration for cooling is that  $0\text{ }^{\circ}\text{C}$  cold water has a much lower cooling capacity than ice at  $0\text{ }^{\circ}\text{C}$ .

Salts of food-grade acids, and here mainly citrate, are occasionally used in conjunction with salt if phosphate is not to be used. Acid salts enhance the swelling of the fibre structure owing to higher ionic strength but do not separate or solubilize actin and myosin as effectively as the combination of phosphates and salt. Citrate is applied at 3–5 g per kilogram of total mass and practical experience shows that a combination of 2 g of phosphates in conjunction with 20 g of salt per kilogram to total mass solubilizes around five times more protein than a combination of 5 g citrate in conjunction with 20 g of salt per kilogram of total mass.

Sausages produced with salts of food-grade acids are generally dull in appearance and the product also commonly lacks bite, firmness and texture, because of the lower amounts of solubilized protein. The risk of obtaining water and/or fat separation in the product during thermal treatment is also higher. The curing colour should develop quickly; so nitrite (see Chapter 7, Section 7.2) is used rather than nitrate. Depending on the maximum level of residual nitrite permitted in the finished product, which differs from country to country, around 150 up to 300 ppm of nitrite are introduced per kilogram of total mass. As a general rule of thumb, around 50–60% of added nitrite acts on colour and flavour development, up to 30% is oxidized to nitrate and a fairly large amount is simply lost, for which there are currently no adequate explanations. For example, if 200 ppm of nitrite are applied per kilogram of total mass in the raw state, around 70–100 ppm are found in the cooked product. Less residual nitrite is found in large-diameter products, because the cooking process is longer than for small-diameter products.

Food standards worldwide limit the maximum level of nitrite permissible in the finished product regardless of the amount introduced during the manufacturing process. In cooked sausages, the level of residual nitrite permitted is typically 80–125 ppm. Some cooked sausages are produced without added nitrite, and this is used as a sales and marketing tool. Spices added to the sausage contain nitrate, and starter cultures such as *Staph. carnosus* are added because they can reduce nitrate to nitrite. The filled sausage is tempered at  $45\text{--}50\text{ }^{\circ}\text{C}$  for 1–1.5 h before final thermal treatment to allow the reduction of nitrate to nitrite and to allow the resulting nitric oxide (NO) to bind effectively to myoglobin to form nitrosomyoglobin.

Colour enhancers (see Chapter 7, Section 7.4) such as ascorbic acid, ascorbate, erythorbate and GDL are used to intensify and speed up the development of curing colour in cooked sausages, and to stabilize the curing

colour during storage. The addition of a colour enhancer only makes sense when nitrite, and not nitrate, is used in the product. Ascorbic acid is added at 0.4–0.6 g per kilogram of total mass while ascorbate, or erythorbate, is added at 0.5–0.7 g per kilogram of total mass. Excess levels of ascorbic acid or erythorbate can cause the product to turn green, while ascorbic acid, or ascorbate, reduces the  $E_H$  value and improves shelf life.

Ascorbic acid is most commonly used as colour enhancer in cooked sausages, because it speeds up the formation of NO, which is needed for the formation of nitrosomyoglobin. Ascorbic acid speeds up the formation of NO from  $\text{HNO}_2$  during the conversion of nitrite into NO (see Chapter 7, Section 7.3). Ascorbic acid also reduces residual nitrite directly to NO and therefore stabilizes the colour in the finished product. By reducing the level of residual nitrite in the finished product, ascorbic acid also helps to keep the product under the legal limit for nitrite.

Ascorbate or erythorbate are converted into ascorbic or erythorbic acid when added to the sausage mass and act as colour enhancers. Care must be taken to ensure that ascorbic acid does not come into direct contact with nitrite, as these two chemicals react instantly with each other to form highly toxic gas. As nitrite is lost in this reaction, the finished product is of very poor and unstable colour and has a shorter shelf life. In severe cases, the product is grey. Generally, colour enhancers containing ascorbic acid or other materials, such as GDL or citric acid, are added to the sausage mass some time after the nitrite. GDL is occasionally added at around 1.0–1.5 g per kilogram of total mass. Citric acid is rarely used and, if so, added at around 0.1–0.2 g per kilogram of total mass. When either GDL or citric acid is added, the pH value of the sausage mass is slightly reduced, which increases the amount of undissociated  $\text{HNO}_2$  thus increasing the amount of NO obtained. Increased levels of NO cause the formation of higher levels of nitrosomyoglobin, thus supporting the development of a stronger curing colour. However, ascorbic acid is more effective for colour development and colour stability during storage than is GDL or citric acid.

Introducing these additives towards the end of the cutting process is beneficial because the pH in the mixture needs to be kept at optimum levels for WHC and protein activation for as long as possible, and sour additives will lower the pH. The addition of GDL or citric acid as colour enhancer should not cause a reduction in pH greater than 0.2 pH units. Another possible problem caused by low pH is fat and water separation.

Ready-made compounds that contain phosphates, ascorbic acid, sugar and spices are frequently used, added as the very first ingredient while salt and nitrite are added afterwards. Ascorbate and erythorbate can be preblended with nitrite, but development of curing colour requires prolonged periods of time for myoglobin to be denatured. Where individual additives are used, preblending of nitrite with materials such as ascorbic acid, GDL or citric acid must be avoided as the moisture content of air is sufficient to cause nitrite reacting with those materials.

Colours (see Chapter 6, Section 6.13) are commonly used in economy cooked sausages, where the amount of lean meat used is low and so colour is added to compensate for the lack of myoglobin. The type of colour introduced depends heavily on the consumers' expectation of the finished product. Paprika oleoresin is generally not used in cooked sausages as it creates an artificial orange colour. The most commonly used colours are carmine, fermented rice and a combination of fermented rice and carmine. Red wine powder, beet red and allura red are occasionally used as well. When using pure carmine, 40–80 mg per kilogram of sausage gives a good colour, but excess levels of carmine result in a deep red and unnatural colour. Fermented rice, depending on the origin, is used at levels of 0.1–0.3 g per kilogram of product. The usage rate of ready-made combinations of carmine and fermented rice, and red wine powder, depends on the blend offered by the manufacturer. Allura red can also be added at around 0.015 g per kilogram of total sausage mass. Occasionally, chocolate brown is utilized as well. Combining ascorbic acid with colours such as carmine or fermented rice results in a fast, strong and lasting curing colour. The colour should be added to the sausage mass right at the beginning of the cutting process in order to ensure even distribution. Blood can be added to cooked sausages as a natural way of increasing colour, but care must be taken to ensure that the bacteria count of the blood used is low.

Different types of sugar are frequently added to cooked sausages, at around 5–15 g per kilogram of total mass. Added sugars round up the flavour and also hide the salty taste if large amounts of salt have been used. The flavour of lactose goes very well with meat flavour, and corn syrup solids with a DE value of around 15–25 are commonly added to products such as hot dogs as a bulking agent to increase the dry-matter content of the product.

Proteins are frequently added to cooked sausages and vast amounts of economy products contain soy protein (see Chapter 6, Section 6.1.4). Soy protein, either isolate or concentrate, contributes to texture, bite and firmness, and isolates also emulsify fat effectively. High-gelling soy proteins should be cut first with water to hydrate the material fully before the meat and fat is placed to the bowl cutter. Specialized low- to medium-gelling soy proteins can be added at the same time as the meat and fat without prior hydration and are also suitable for mixer–emulsifier systems where all additives are added to the meat and fat materials in a mixer. The amount of soy protein added to cooked sausage varies enormously, and levels between 1% and 14% are found. High amounts of soy protein in a sausage increase the pH slightly, which raises WHC. Soy protein is frequently used in cooked sausages to compensate for the use of less expensive, or more fatty, ingredients. Another method of lowering the cost of cooked sausage is to replace some of the lean meat with a mix of soy isolate and water in a ratio of 1:3. Soy isolate contains around 90–92% protein and every 4 kg of lean meat taken out of a recipe can be replaced with 1 kg of soy isolate and 3 kg of water. However, replacing lean meat with soy protein and water affects texture, firmness,

flavour and bite, since meat protein contributes very positively to these parameters. The degree of substitution depends largely on the desired cost structure of the cooked sausage being produced. Soy concentrate also works well in emulsified sausages as the insoluble fibres, besides the protein, interact well with solubilized meat protein and synergistic effects are seen.

Non-injectable pork rind powder is occasionally added to cooked sausage because it contributes to firmness and texture, and 5 g per kilogram of product is effective. However, skin emulsion achieves a similar effect, as both materials are rich in collagen. Egg protein is commonly used in low-cost frankfurters, at amounts between 1% and 2%, as it forms a heat-stable gel once denatured.

Frozen blood plasma is another protein used in the production of cooked sausage owing to its excellent WHC; around 2% is the maximum amount added, and it is introduced at the same time as ice/water. Blood plasma binds added water even more effectively than meat protein and has a pH of around 7.3–7.5; so it raises the pH in meat, leading to an increased WHC. Products containing blood plasma should reach a core temperature of 72 °C, as plasma forms a solid gel at such temperatures. The blood plasma must be counted towards the total water content of a sausage because it contains water, and so the amount of water, or ice, added has to be adjusted (reduced). Blood plasma today is also offered in a concentrated version of around 19–21% protein, which is very similar to that of lean meat. Frozen or fresh blood plasma is added to the sausage mass during the initial stage of cutting. Dried blood plasma has around 72% protein and very little water and is added at the beginning of the cutting process. It can hold up to ten times its own weight in water and forms a solid gel. If used, 3–6 g of dried blood plasma are added per kilogram of total mass at the beginning of the cutting process.

Spices, spice extracts, herbs and HVP are added according to the desired taste and there are a limitless number of possible combinations of flavours. Generally, spices are added at 3–5 g per kilogram of sausage, and flavours, based on spice extracts or oleoresins, are applied at a much lower rate. Spices commonly used are nutmeg, ginger, white pepper, mace, onion powder, cinnamon and garlic, among others. Dark-coloured spices are avoided because they can be seen as small dark particles in the finished product. Liquid smoke, or powdered smoke flavour, is added to non-smoked cooked sausages where a touch of smoke flavour is desired. Liquid smoke is added preferably at the end of the emulsifying process, because otherwise the acids in the liquid smoke (phenols) would interfere with protein activation.

Carrageenan (see Chapter 5, Section 5.3.3) is regularly used in amounts of 1–3 g per kilogram of total mass in recipes containing large amounts of water and little meat owing to its enormous WBC, together with ability to reduce purge in packed products. Cold-swelling gums such as guar are occasionally used as well to reduce, or eliminate, purge in packed products.

Starch is very common in cooked sausages and the amount used varies between 20 and 100 g per kilogram of total mass. Starch is used for its ability to bind water and also for its contribution to firmness and texture of the product, especially in sausages with a low meat content. Starch also acts synergistically with activated meat protein. The most economical and readily available type of starch is frequently used, despite the different technological behaviours (see Chapter 6, Section 6.2.2). Using starch reduces the risk of water separation in the product during thermal treatment and also reduces the amount of purge in sliced vacuum-packed products. Other carbohydrate-based fillers such as rusk, flour and cereal binder are used in cooked sausages chiefly for their WHC as well as because they are economical, and the amount added varies between 20 and 100 g per kilogram of sausage mass.

Lactate (see Chapter 5, Section 5.2.2) is frequently used to extend shelf life and is added to the sausage during the initial stage of the cutting process once the salt and all water and ice have been added. In some countries, such as the USA, almost all cooked sausages contain this additive for microbial control. A blend of lactate and (di)acetate controls the growth of *Listeria monocytogenes*, which is of vital importance in some countries because products containing significant amounts of *L. monocytogenes* have to be recalled. Lactate is generally added at around 30 g per kilogram of total mass, and 25 g per kilogram of total mass for the lactate–acetate blends. If lactate is included in the recipe, it should be added to the sausage mass after all the water and ice have been added and well bound, but definitely in the first half of the cutting process. The early addition of lactate enhances ionic strength and more protein is activated as a result. If lactate is added very late in the process, the impact on enhancing the ionic strength is significantly reduced because fat, starch or other materials are present in the emulsion as well. In addition, lactate is able to immobilize water at an amount of around 60% of its own weight, thus contributing slightly to a firmer bite of the finished product.

Emulsifiers are rarely used in cooked sausages as they only work effectively in real emulsions, where fat and water are both present in liquid form, which only applies for cooked sausages when oil is the source of fat processed. In all other applications, emulsifiers slightly reduce the risk of fat separation in the product during thermal treatment, and monoglyceride and/or diglyceride are added at around 3 g per kilogram of total mass. Flavour enhancers such as MSG or ribonucleotide (see Chapter 6, Sections 6.5 and 6.6) are frequently added to cooked sausages as well.

## 12.5 Manufacturing technology

The system for manufacturing cooked sausages is highly complex because of the number of raw materials, additives and types of machinery used. The end result should be a homogeneous, finely cut smooth-textured product,

which can withstand thermal treatment without the separation of fat or water showing firm texture and good bite.

### **12.5.1 Emulsification**

Emulsification of fat and immobilizing added water in a meat product at the same time is a complicated process. The aim of the manufacturer of cooked sausages is to solubilize as much protein as possible, because solubilized protein immobilizes added water and emulsifies fat at the same time. Solubilized protein creates a thin layer around the finely cut particles of fat, which prevents separation of fat during thermal treatment. The thickness of the layer of protein covering the particles of fat determines to a large degree the stability of the emulsion, and thicker layers of protein are better. In activated or solubilized protein, myosin has a greater tendency to emulsify fat than has actin, which shows a higher affinity towards water. During thermal processing, the layer of protein surrounding the fat particles is denatured and the fat is kept in the layer of protein, forming a three-dimensional matrix. This network of protein also prevents fat particles from unifying with other fat particles. Salt-soluble proteins such as actin and myosin have greater fat emulsification capacity than water-soluble proteins.

The amount of protein solubilized depends firstly on the amount of protein present in the sausage mass, which in low-meat products is not always sufficient. The amount of protein solubilized also depends greatly on the types of additive used, and additives such as phosphates and salt play a critical role. Also, as explained in Section 12.4, the amount of salt added relates directly to the amount of protein solubilized. Salt increases ionic strength, and maximum protein solubility occurs at a salt concentration of around 5% added salt, which is not acceptable from a taste point of view. The amount of protein solubilized also depends on the amount of energy introduced during processes such as cutting and emulsifying. In cutting, the terms 'overcut' or 'undercut' are frequently discussed as they refer to the degree, or severity, with which energy was introduced into the meat to activate protein. Generally, a cooked sausage should be cut for long enough that no fat particles are visible in the emulsion and at the same time should ensure that as much protein has been activated as possible. Undercutting occurs if the cutting or emulsifying process is too short, in which case the fat is insufficiently comminuted and visible particles can be seen in the final product. A short cutting process does not activate the optimal amount of protein and so there is only a thin layer of activated protein covering large particles of fat during heat treatment. This results in an elevated risk of obtaining fat and water separation during thermal treatment. Overcutting is when the sausage mass is cut for too long, and this results in too large a fat surface area, owing to the countless very small particles of fat in the emulsion. Generally, smaller particles of fat are easier to emulsify than larger particles, but there is only a certain amount of activated protein to cover the surface of the fat particles.

Here again, the layer of protein around individual fat particles is thin, increasing the risk of fat separation during thermal treatment and reducing the stability of the emulsion.

In an emulsion, several interactions take place. The main ones are protein–water, protein–fat and protein–protein interactions. Technologically speaking, the protein–water interactions are of the greatest interest as they have a major impact on swelling and solubilization of protein, as well as holding added water. Protein–fat interactions are very important as well and protein–protein interactions are chiefly responsible for the thickness of the layer of protein covering the fat particles.

Generally, three different systems are used to produce emulsified cooked sausages. One uses only the bowl cutter, the second uses a bowl cutter and an emulsifier, and the third uses a mixer–blender system.

#### *Emulsifying with a bowl cutter*

Working with a bowl cutter, or the combination of a bowl cutter and an emulsifier, is based on batch production and is a non-continuous process. A bowl cutter is a machine where cutting takes place in a circular, curved and slowly rotating bowl. The meat and fat mass is carried anticlockwise towards a set of rapidly rotating knives. At least six knives should be used for manufacturing cooked sausages. The knives should be kept sharp and rust free and be adjusted so that they are fully balanced during rotation.

Contrary to common belief, it is not necessarily essential to have sharp knives to obtain a stable emulsion and to activate high amounts of protein. Stable emulsions have been obtained using non-sharpened knives, and the protein is activated in a non-cutting action (see below) in the secondary phase of creating an emulsion. It is critical to balance the knives because they rotate at speeds up to 6000 rev/min and any imbalance would seriously damage the machine. The knives also have to be adjusted so that the gap between the bowl and the knives is as little as possible and there should be no wide gaps between knife and bowl. Essentially, the knives must be able to turn freely without touching the wall of the bowl but should be as close as possible to the wall at the same time.

In large-scale production, it is common practice to carry out online analysis of the fat content of a batch being processed in order to standardize every single batch. If a large batch contains more protein, or lean meat, than specified in the recipe, the costing of the sausage will be incorrect and money would be lost because lean meat is more expensive. If there is not enough protein in the batch, there is a greater risk of fat and water separation and the firmness of the sausage will be poor. In both cases, the finished product will not be standard, which is a problem because customers today demand consistent product quality.

Peeling of skinless sausages such as frankfurters can be more difficult if the fat within the product is very finely cut or large amounts of collagen-rich materials such skin emulsion are used. High levels of starch within the product also can have a negative impact on ‘peelability’.

There are three different methods for working with a bowl cutter.

- 1 Lean-meat method.
- 2 All-in method.
- 3 Fat method.

The correct, or optimal, cutting process to create the most stable emulsion is still heavily debated among experts. The optimum cutting time is as short as possible in order to save energy while being long enough to ensure that as much protein as possible is activated and that fat is cut enough that it is not visible in the finished product. Prolonged cutting of fat should be avoided because it creates a large surface area, thus reducing the stability of an emulsion. Optimum cutting depends on a range of parameters, including the amounts of meat, fat and water in the recipe, the types of meat and fat processed, and the machinery available. No universal formula for optimum cutting time can be established as a result of the great variations in ingredients, recipes and methods.

The total cutting procedure in a bowl cutter can be divided into two phases. The first phase begins when the functional additives and water (or ice) have been added to the meat and fat. During this initial cutting, the temperature of the sausage mass is between  $-1$  and  $3$  °C and its viscosity is low.

Most of the protein activated during this phase is activated by the cutting of muscle cells, destroying large amounts of sarcolemma. Additives such as phosphates and salt, in conjunction with added water (ice), start to solubilize myosin and actin by turning these fibrous proteins into a liquefied material. After a period of cutting and solubilizing, the viscosity of the sausage mass increases and, as the temperature rises to  $4-6$  °C, shearing forces come increasingly into play. From this stage onwards, the protein is activated by shearing forces rather than cutting and, overall, shearing forces are responsible for most of the total protein solubilized. This explains how a stable emulsion can be obtained using fairly blunt knives, because blunt knives create large shearing forces, solubilizing large amounts of protein. However, working with sharp knives is better because protein is also activated effectively during the initial phase of cutting.

The bowl should be at least 50% full in order to create sufficient shearing forces during the second phase of emulsification. Higher filling is more efficient as greater shearing forces are obtained, and the bowl can be filled up to 90% of total capacity.

#### *Properties of differently shaped bowl-cutter knives*

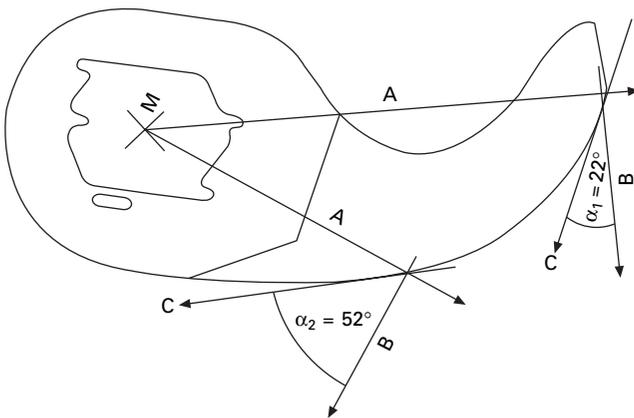
The shape of bowl-cutter knives has changed dramatically over the last few years. Much research has been carried out into developing cutter knives that activate greater amounts of muscle protein in a shorter period of time. The knives turn extremely quickly, up to 5500–6000 rev/min; so enormous forces must be withstood while, at the same time, achieving a high impact on the protein and the mass in the bowl. Sharpening bowl-cutter knives is an art on

its own, and all cutter knives are sharpened on one side only. The sharpening angle on bowl-cutter knives is generally around  $27\text{--}28^\circ$ , on the bevelled side of the knife only. When resharpened, the original angle has to be maintained so that the knives are balanced when they are reinstalled in the bowl cutter. If a cutter knife is sharpened on both sides, the temperature of the sausage mass would rise significantly more quickly than if the knife was sharpened on one side only. During emulsification, the temperature should not rise quickly, as this shortens the time available for activating protein and the comminution of fat. Different angles on the sharp side of a knife have different impacts on cutting the sausage mass.

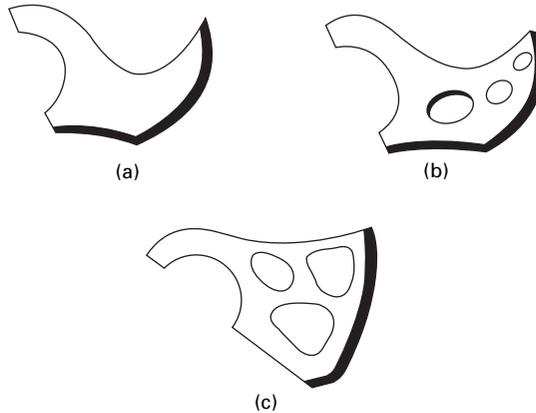
As shown in Fig. 12.1,  $\alpha_1$  is an angle of  $22^\circ$  and the sausage mass, or muscle fibre, is cut at all points with an angle less than  $40^\circ$ .  $\alpha_2$  is an angle of  $52^\circ$ , and all points with an angle greater than  $40\text{--}45^\circ$  contribute to shearing and little cutting takes place. Specialized cutter knives that create strong shearing forces rather than cutting forces can be used.

Figure 12.1 also shows how to determine the angle on the knife that distinguishes between cutting and shearing forces. In order to determine such an angle, a line is drawn from the centre of the knife (M) to the set point of the sharp side (line A). Another line is drawn at a  $90^\circ$  angle to line A at the same point (line B) and finally a third line (line C) is drawn through the set point, which gives the angle.

Some bowl-cutter knives have holes in the blade, and the holes create even greater shearing forces. Newly developed bowl-cutter knives have a range of shapes and Fig. 12.2(a) shows a standard knife, Fig. 12.2(b) a knife with holes in the knife itself and Fig. 12.2(c) a hacking–cutting knife, one of the latest designs, which does not resemble the traditional shape of a knife. Hacking–cutting knives have been developed to activate protein very efficiently and to increase productivity, because the shortened processing period allows more batches to be made in a given period of time.



**Fig. 12.1** Determining the cutting or shearing forces created by a knife.



**Fig. 12.2** Types of knife: (a) a traditional bowl-cutter knife; (b) a knife with holes; (c) a whole-hacking knife.

### 12.5.2 All-in method

As the name suggests, this method of obtaining a sausage emulsion starts with all meat and fat materials in the bowl cutter, including fat or skin emulsions if used. Cutting starts at slow to medium speeds, around 1000–1500 rev/min. Once cutting has started, all the functional additives (phosphates, salt, binders and starch) are added, usually in the form of a compound or complete mix. Immediately afterwards, the water and ice are gradually introduced and the knives are switched to fast speed. Water, and/or ice, should not be added before the functional additives because the additives should come in contact with the protein at the highest possible concentration. If large amounts of water and ice are part of the recipe, the water and ice are added gradually to prevent the meat from becoming too sloppy, which would require longer cutting to build up some degree of viscosity. Usually, around 70% of the total water and ice is added first and after a short while, when it is well incorporated into the mass, the remaining 30% is added. Moderate levels of added water and ice can be added at once. At this point, the temperature of the sausage mass should be between approximately  $-1$  and  $2$  °C and the speed of knives around 3500–5500 rev/min. The water and ice act to maintain the desired temperature range from  $-1$  to  $4$  °C for a prolonged period of time for maximum solubilization of protein during the first phase of cutting. If chilled meat and fat materials, with a temperature around  $0$ – $4$  °C, are being processed, more ice will be required to keep the temperature in the acceptable range. If some of the meat or fat materials are being processed semifrozen or frozen, more cold water can be used instead of ice to maintain the desired temperature.

Meat and fat materials are occasionally cut for a short while with all the functional additives, and this dry cutting destroys a large amount of sarcolemma. Water and ice are added once a tacky mass is obtained, to cool it to approximately  $-1$  to  $2$  °C. Dry cutting can cause rapid rises in temperature;

so this must be monitored carefully. In the case when the temperature of the sausage mass drops too low, i.e. when the water and especially ice are added excessively, the sausage mass is cut at a slow to medium knife speed until the temperature rises to between approximately  $-2$  and  $0$  °C. Cutting the entire mass at a high speed at temperatures below  $-2$  °C damages, and partly denatures, muscular protein and so less protein will be activated. If the temperature is well below  $-2$  °C during the first stage of cutting, it takes a long time to raise the temperature to the optimal range and the fat is cut for too long. This results in a large fat surface area, which reduces the stability of the emulsion and also results in a soft-textured product. Generally, manufacturers who use the all-in method are very familiar with the type as well as the temperature of materials being processed and the system is designed so that the optimal temperature range during the initial stage of cutting is obtained consistently. When a temperature of around  $0$  °C is reached, the knives are switched to a faster speed, and cutting continues until a temperature of  $12$ – $14$  °C is reached, which completes the process. At a temperature of  $12$ – $14$  °C, the vast majority of the fat is still present as fat, and little or no fat has melted. Melted fat is harder to emulsify and also has a large surface area, which increases the risk of fat separation in the finished product.

A compound of additives is commonly used to keep the process as simple as possible. Occasionally, the additives are introduced in two steps, with phosphates, salt, nitrite, carrageenan and spices being added at the beginning of the process to ensure optimal protein solubilization and an even distribution of nitrite and spices. Bulking agents, starch or binders are introduced later in the cutting process, when the temperature of the mixture reaches  $8$ – $10$  °C. If a large amount of binders are added at the beginning of the cutting process, they utilize some of the free water, which is required for protein solubilization. However, this slight technological disadvantage is commonly ignored and everything is added at the beginning to keep the process as simple as possible.

Most bowl cutters today have two or three bowl speeds (turns per minute). A fast bowl speed is usually selected when the knife speed is high. The all-in method often starts with processing frozen or tempered blocks of fatty meat, which removes the problem of time and space required for defrosting. The frozen material is flaked or cut into cubes with a guillotine or minced in a mincer especially designed to cope with frozen meat. The cut or minced meat and fat materials are then placed in the bowl cutter and the additives are mixed in. Warm water, up to  $45$  °C, is occasionally added to raise the temperature of the mixture to around  $0$  °C in the case when frozen materials are processed and the meat and fat material defrosts in the cutter. When the temperature reaches around  $0$  °C, the knives are switched to fast and the sausage mass is cut until the temperature reaches  $10$ – $14$  °C. An alternative method using frozen raw materials is to temper the frozen block of meat and fat in the chiller for  $1$ – $2$  days. This means that ordinary tap water can be used during cutting instead of slightly warm water. Whichever method is used,

there is no thawing loss and the microbiological risks associated with thawing are eliminated. Large-scale manufacturers standardize parameters such as the protein, fat and water content of the sausage mass, the temperatures of all materials used and the temperature of the ice or water to ensure consistency. Hence, the addition of water or ice is based on the temperature of meat and fat materials processed in order to obtain a temperature of between approximately  $-1$  and  $2$  °C at the beginning of the cutting process. This standardization also means that even non-skilled personnel can operate the bowl cutter. Frequently, the cutting process stops automatically once a set temperature, e.g.  $14$  °C, is reached, and the staff operating the machine simply have to ensure that all raw materials, additives and water or ice are added in the correct amounts and at the right time, and the rest takes place automatically.

Standardization of the process is important because variations in temperature can cause problems when the process is based on a set final temperature. If the temperature of the raw materials or the water or ice is higher than normal, the predetermined final temperature will be reached more quickly and the mixture will have had insufficient cutting, possibly leading to visible fat particles in the emulsion and less activated protein. This results in a less stable emulsion, increasing the risk of fat and water separation during thermal treatment. If the temperature of the raw materials and water or ice is too low, it will take longer to reach the set final temperature. Prolonged cutting means that the fat will be cut more finely and the finished product will be a lighter colour. The large fat surface area due to prolonged cutting will reduce the stability of the emulsion because the activated protein will have to cover more fat surface. This increases the risk of fat and water separation in the finished product and reduces firmness at the same time.

The all-in method can also be standardized to a set period of cutting time rather than temperature. If the desired final temperature is not reached in this time, then the shearing forces during the second stage of emulsification will be lower. This causes less protein to be activated; so the risk of fat and water separation in the product during thermal treatment is increased. If the starting temperature of the sausage mass is above the normal level, then having a set time for cutting can mean that the final temperature is too high, which again increases the risk of fat and water separation.

The main advantage of the all-in method is that it is simple and so non-skilled people can operate the bowl cutter easily. The process can be standardized to the point where the operator needs only to push a start button, and the entire process then automatically follows a predetermined program entered into a computer connected to the bowl cutter. This total standardization means that the finished product is more or less always the same and very consistent in texture, bite, firmness, colour and taste despite its simplicity.

The disadvantage of the all-in method is that fat is present in the bowl cutter right from the beginning of the cutting process, and makes additives

such as phosphates and salt less effective at solubilizing protein. Having fat present from the beginning also means that the fat is cut for a long period of time, and this makes the fat surface area that has to be covered by activated protein much larger. The finished product in this case will be softer in texture and, if there is too little protein present, the risk of fat and water separation is increased. A large fat surface area also makes the finished product lighter in colour than if the same recipe were processed using the lean meat method (see below).

Figure 12.3 shows the temperature curve for the all-in method.

### 12.5.3 Lean-meat method

The lean-meat method starts with lean muscle tissue, around 85–95% CL grade, which is cut at a medium knife speed to begin with. If MDM is included in the recipe, it is also placed in the cutter right at the start of the cutting process. The lean meat can be well chilled, slightly frozen or even be fully frozen (flaked or minced). If chilled meat is used, a temperature of 0–4 °C is optimal. Premincing with a 3–5 mm blade is recommended as protein activation occurs more quickly in minced meat because of the large surface area. A separation unit can be attached to the mincer to remove particles of bone, cartilage and tendon during mincing so that the resulting lean meat is free of these undesirable materials.

When frozen or semifrozen meat is used, not much ice is required and most of the water added to the sausage mass afterwards can be simply cold water. If chilled lean meat is processed, then more ice is needed.

The cutting process for lean meat starts at a knife speed between 1000 and 1500 rev/min. Functional ingredients, such as phosphates and proteins (or a protein gel), are added and the mixture is cut until the mass reaches a tacky consistency. During this dry-cutting period, a fair amount of protein is activated owing to the high shearing forces. Dry cutting cannot be continued for too long because the temperature rises quickly and proteins will be denatured. Once a tacky consistency is reached, and the temperature of the cut lean meat is still below 10–12 °C, around 60–70% of the total water (as ice or a

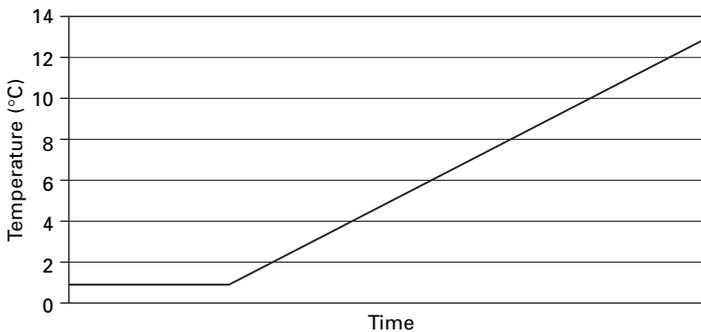


Fig. 12.3 Temperature change during the all-in method.

mix of ice and water) is added. Salt is added immediately afterwards and this reduces the temperature to between  $-2$  and  $2$  °C. The knife speed is increased to fast and the mixture is cut until a temperature of around  $4$  °C is reached. Using frozen or semi-frozen meat, as mentioned above, requires more cold water than ice to obtain the desired temperature range. Using chilled water rather than ice is generally cheaper.

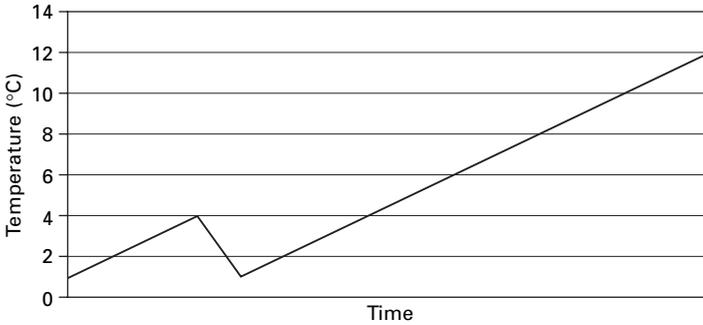
When the temperature of the lean meat emulsion reaches around  $4$  °C, the remaining ice is added to bring the temperature down again to around  $0$  °C. All the water and ice are added before the fat is introduced so that the maximum amount of protein is solubilized by the salt and phosphates. After the ice has been added and the temperature has fallen to  $0$  °C, the chilled and minced fat is added. It is important to mince the fat before it is added to the cutter if a bowl cutter with a low maximum knife speed is used. The fat does not need to be preminced for bowl cutters that rotate at  $4000$ – $5000$  rev/min. However, it is advantageous to use preminced fat and a slower knife speed,  $3500$ – $4000$  rev/min. If the knife speed is above  $5000$  rev/min, the sausage mass would become severely beaten and the final texture would be softer owing to the partial destruction of protein and collagen. If the bowl cutter has a maximum speed of only around  $2000$ – $2500$  rev/min, the fat should be preminced because otherwise it will not be cut enough in the bowl and small fat particles could be visible in the finished product.

An alternative is to add non-minced frozen fat to the lean meat emulsion at around  $0$  °C. This reduces the temperature to around  $-2$  °C. At such low temperatures, a fairly long cutting time is required to reach the final temperature, and so the fat will be emulsified sufficiently to ensure that no visible fat particles are present in the finished product. Once the fat (or jowl) is added to the lean meat emulsion, the mixture is cut at a knife speed between  $3000$  and  $4500$  rev/min until the desired final temperature is reached, generally between  $10$  and  $14$  °C. Binders are generally added to the emulsion at a later stage at around  $8$  °C in order not to interfere with absorption of water and protein activation, as described above. Colour enhancers and spices can also be added earlier, for instance when the fat is introduced. Ascorbic acid, if used, must not be added at the same time as nitrite.

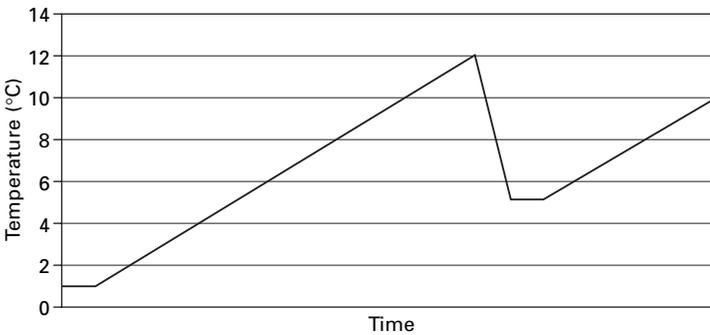
If fat and skin emulsions are used in this method, they are treated like fat and are added after the protein has been activated.

Figure 12.4 shows the temperature curve for the lean-meat method.

A variation of the lean-meat method is to add around  $70$ – $75\%$  of the total water and ice to the lean meat at the beginning of the cutting process, after the functional additives. This results in an optimal temperature in the approximate range from  $-2$  to  $2$  °C. The fat is then added and the mixture cut under high speed up to around  $12$ – $14$  °C. Binders are added at around  $8$ – $10$  °C and, when the temperature of the meat mass reaches  $12$ – $14$  °C, the remaining  $25$ – $30\%$  of ice are added, which causes the temperature to drop back to around  $4$ – $6$  °C. Cutting at a high speed continues until the temperature reaches  $10$ – $12$  °C again, which completes the process.



**Fig. 12.4** Temperature change during the lean-meat method.



**Fig. 12.5** Temperature change during the alternative lean-meat method.

Figure 12.5 shows the temperature curve for this alternative lean meat method.

From a technological view, introducing all the water and ice before any fat makes more sense as all the water is available to solubilize the protein. Adding ice to the emulsion when the fat is already finely cut has a slight disadvantage that added water must be immobilized in an emulsion also containing fat instead of all being added into concentrated protein only. However, both methods are common and both produce acceptable results.

The advantage of the lean-meat method is that functional additives such as salt and additives act directly on the muscular protein, without the presence of fat or other non-meat materials; so the maximum amount of protein is activated. Elevated levels of activated protein create a more stable emulsion, creating a firmer texture and reducing the risk of fat and water separation. Because the fat is added later in the cutting process, the degree of comminution is lower than for the all-in method and therefore the surface area of fat remains smaller. The curing colour in the finished product is stronger than that in the all-in method because the surface area of the fat is smaller.

The disadvantage of the lean-meat method is that several steps are involved in the process and therefore the staff operating the bowl cutter needs to be

skilled. The process is simplified by using compounds, or complete blends, of additives. The compounds commonly contain functional ingredients such as phosphates, colour and flavour enhancers, spices, protein (if required), starch and other fillers and occasionally even all the salt. Nitrite is not included in compounds where the colour enhancer used is ascorbic acid, GDL or citric acid for the reasons described earlier (see Chapter 7, Section 7.4). Nitrite can be included in the compound if other colour enhancers such as erythorbate or ascorbate are used, because these do not react with the nitrite. The compound is added to the lean meat at the beginning of the cutting process. Colour enhancers such as GDL or citric acid (if used) are added separately, preferably in the last third of the process. Another benefit of using additive compounds is that the manufacturer of the compound is responsible for ensuring that the levels of phosphates, and especially nitrite, are correct, rather than staff at the meat-processing company. This also reduces storage space and makes ordering simple because only one item (the compound), rather than separate additives, needs to be ordered and stocked. Additive compounds can be packed in amounts that correspond to the batch to be processed, so that the operator is not required to weigh ingredients.

Nitrogen and water can be used instead of ice and the temperature of the sausage mass, using the lean-meat method, can be maintained at around 0 °C during the entire cutting procedure. The introduction of nitrogen keeps the temperature low, and cutting continues until a fine homogeneous mass is obtained with no visible particles of fat. Cutting at low temperatures is beneficial because the solubility of actin and myosin is excellent at around 0 °C and so sufficient protein is activated despite the lack of high shearing forces. Cutting under such low temperatures results in a stronger red colour than a sausage produced under the conventional lean-meat method. This is because the gradual addition of nitrogen forces oxygen out of the sausage mass, and so NO binds more quickly and more effectively to myoglobin to form nitrosomyoglobin. However, working with nitrogen adds cost to the product and is therefore not often practised.

The timing of adding fat to the lean-meat emulsion in the lean-meat method has an impact on the final product. If the fat is added in the early stage of the cutting process, it is cut for a long period of time and the resulting large fat surface area leads to a lighter colour and a softer texture in the final product. If the fat is added too late, it might not be sufficiently cut and fat particles will be visible in the final product, greatly enhancing the risk of fat separation during cooking.

#### *Cutting and mixing under vacuum*

Applying a vacuum during cutting is advantageous because more protein is activated, which increases the stability of the emulsion itself and also contributes positively to firmness and texture of the emulsion. Processes such as protein swelling and solubilization take place more rapidly under a vacuum than in

atmospheric pressure, because atmospheric pressure acts as a counter-force against swelling.

During high-speed cutting, especially during the second stage of the cutting process when the predominant forces are shearing, large amounts of air are introduced into the sausage mass. This reduces firmness and colour stability of the finished product. Removing oxygen (O<sub>2</sub>) allows NO to bind more quickly and more effectively to myoglobin to form nitrosomyoglobin and enhances curing colour because the density of the sausage mass created under a vacuum is higher. Even if a vacuum filler is used during filling of the sausage mass, it will only remove the majority, but not all, of the air trapped in the emulsion if no vacuum was applied during cutting. Applying a vacuum during cutting as well as during filling, results in an air-free product with better firmness and texture.

A vacuum from around  $-0.7$  to  $-0.95$  bar is generally applied during the last third of the cutting process, when high shearing forces are the primary method of activating protein. Care should be taken to ensure that the vacuum is always the same strength, especially for the production of portioned sausages, which should all be the same weight and length. If the vacuum is higher than normal, then the sausage mass will be denser and, if a certain weight is filled into small-diameter casings, the sausages will be shorter than the standard. Adding an inert gas such as nitrogen (N<sub>2</sub>) after emulsification is one option for standardizing the density of the sausage mass prior to filling.

#### *Cooked sausages with visible meat and fat particles*

Visible particles of meat and fat in a cooked sausage are mixed into the fine emulsion. The materials used for visible particles, or show-meat, should preferably be precured so that their colour is fully developed before they are added to the emulsion. Meat and fat materials, or fatty trimmings, to be used as show-meat are treated with around 16–20 g of salt per kilogram of product and around 150–250 ppm of nitrite per kilogram at least 12–24 h before use and stored under chilled conditions. A strong red curing colour develops during this time. The precured materials are subsequently minced with the desired blade and gently mixed into the fine emulsion.

Care must be taken to ensure that the temperature of the minced precured show-meat is similar to the temperature of the finely cut emulsion when they are mixed together, to avoid water separation in the finished product during cooking. If, for example, the minced precured show-meat is at a temperature of 2 °C and the emulsion is at 14 °C, when both materials are mixed together, the risk of water separation during cooking, especially if the product is filled into a waterproof casing, is high. When the temperatures of the show-meat and the emulsion are similar, binding is strong and slice coherency is good. The risk of water separation during cooking is also influenced by the size of the show-meat particles. Larger particles will present a smaller surface area in relation to their weight for binding than smaller particles and therefore enhancing the risk of water-separation.

Fine emulsion products containing visible show-meat are commonly made by mincing precured 75–80% CL grade trimmings with a 4–8 mm blade. Between 15% and 40% of pre-minced trimmings are mixed with 60–85% fine emulsion. Care should be taken to ensure that the fine emulsion contains the correct amount of spices for the total mass, which includes spices added to the show-meat as well as to the emulsion.

Show-meat does not need to be precured if all the salt, nitrite and colour enhancer required in the finished product are added to the emulsion. For example, if the total sausage mass is made from 70 kg of fine emulsion and 30 kg of show-meat, then salt, nitrite, colour enhancer and spices sufficient for 100 kg are added during the preparation of the 70 kg emulsion. Then the raw and uncured show-meat is minced with the desired blade and gently mixed into the emulsion. Sufficient time must be allowed for the curing colour to develop before thermal treatment; otherwise the show-meat may be grey in the finished product. If the show-meat particles are larger than 8 mm, they should be precured because it will take too long to develop a strong and stable curing colour if they are not precured. Smaller show-meat particles, which have been minced with a 3–5 mm blade, can be used uncured as long as the finished product is tempered for around 30–45 min at 50–55 °C to allow colour development before proper thermal treatment begins. Colour enhancers are also beneficial if uncured show-meat is used. If manufacturers wish to avoid the colour development phase prior to thermal treatment of the product, or the risk of poor colour in the finished product, then all show-meat should be precured, regardless of final particle size. The only material used for show-meat where it is not vital to precure is fat, as fat does not develop curing colour. However, fat is commonly precured because this reduces the amount of smearing during the mincing process. Meat and fat materials to be used for show-meat should be minced together, again to prevent smearing, which can lead to fat separation in the finished product.

Cooked sausages, and primarily cold cuts, often have lean and large pieces of show-meat which have been tumbled before being mixed into the emulsion (see Chapter 13, Section 13.8). Mixing a finely emulsified sausage mass with visible pieces of show-meat of any size should be carried out under vacuum to remove air from the product, thus contributing positively to firmness, texture, bite and colour stability.

#### **12.5.4 Fat method**

The fat method is purposely used for one type of cooked sausage, Bavarian white sausage, or weisswurst. This product does not conform to the normally desired characteristics of a cooked sausage, such as a firm texture and a good bite. It is said that weisswurst resembles the ‘total failure’ of a cooked sausage. The lean meat used for weisswurst is pork, or a mixture of pork and veal, and it contains a high level of added water and a fair amount of fat. The product is not cured and should have a very sloppy, wet and non-firm texture.

The saying in Germany is that 'weisswurst should be made in the morning and should be eaten before 12 noon', together with a bretzel (a certain type of bread), mustard and, of course, a white beer (Germans enjoy their beer). This saying is based on the very short shelf life of the product because no nitrite is present and the water content is high.

The fat method starts with cutting chilled pork fat in the cutter at a high knife speed, without any additives or water, until the temperature reaches around 10 °C and a fluffy and finely cut mass of fat is obtained. The fat is removed from the cutter and replaced with lean meat. The lean meat is cut at a medium–fast speed and additives such as phosphates, salt and spices are introduced.

Weisswurst does not contain additives such as starch, proteins or gum. Around 70% of the total ice and water is added, bringing the temperature of the lean meat mass down to around 0 °C, and the knives are switched to fast. The lean-meat emulsion is cut at a fast speed to around 4 °C, when the remainder of the ice and water is added. The temperature drops to around 0 °C and the fluffy fat is added. The entire sausage mass is cut at a high speed to a temperature of around 12–14 °C, which completes the process. Fresh parsley is often added at around 10–12 °C so that it is cut for a short time but still visible in the finished product. This method is basically the lean-meat method, with the only difference being the addition of very finely cut fat to the lean-meat portion. Creating an extremely large fat surface area in this way contributes to the soft bite of the finished product, and the large amount of water added contributes to a soft and mushy texture.

### **12.5.5 Cooked sausages made with oil**

Cooked sausages are often made using vegetable oil because beef or pork fat cannot be consumed by many people for religious reasons. People who cannot eat pork can eat, for example, frankfurters made from beef and vegetable oil, and those who cannot eat beef can have cooked sausages made from pork or chicken meat and oil. The combination of chicken thigh meat with oil results in a very nicely textured finished product.

Cooked sausages made with oil have a lovely red curing colour and a combination of beef or pork with oil results in excellent finished products. Oil consists of almost 100% fat and therefore the amount of oil within the recipe will be less than if, say, pork fat is used because pork fat actually contains around 85% fat.

The technology for working with oil is very similar to the lean-meat method, with just a few very important differences. Lean meat is cut at a medium speed with additives (phosphates, salt, nitrite and spices) and around 70% of the total water and ice. The temperature drops to around 0 °C when the water and ice is added, and the knife speed is switched to fast. When the temperature has risen to around 4–6 °C, the remaining 30% of water and ice is added, bringing the temperature back to around 0 °C. After cutting at a fast

speed for a short while, and once the temperature starts to rise again, the chilled oil is added gradually while cutting continues.

The oil is not all added at once because the solubilized protein has to act on a very large surface area to emulsify the oil, and this takes time. Adding the oil gradually to the activated protein ensures that it is emulsified properly. The oil should be added at such a speed that all the oil has been added by the time that the temperature of the sausage mass reaches around 3–5 °C. Starch or other fillers are added (if applied) once the added oil is fully emulsified, which is visible at around 6–10 °C. During the emulsification of the oil, the sausage mass changes visibly from being sloppy and darkish into a firm and light-coloured mass. Cutting under a high speed stops at a temperature between 8 and 12 °C when the added oil is well emulsified and further cutting took place for a short while afterwards. It is essential that chilled oil, around 1–4 °C, is used in the process to keep the temperature down and to allow the oil to be effectively worked into the sausage mass.

### **12.5.6 High-salting method**

The high-salting method is used for products such as frankfurters in brine, which are commonly packed in glass containers and retorted. If such sausages are processed in a bowl cutter, both the lean-meat and the all-in methods can be used, but the lean-meat method is the most common. The meat materials to be processed must not be too rich in connective tissue because it is rich in collagen, which will swell during severe heat treatment, causing the sausages to burst.

The amount of salt added during the manufacture of the sausage emulsion in this method is twice that in a regular sausage, at around 4% of salt, or 40 g per kilogram of total mass. This level of salt would not be tolerated by the consumer in a regular sausage. The sausage mass is generally filled into natural sheep casings with a diameter between 22 and 24 mm, and further processing steps include drying at around 60 °C for 15–20 min in low humidity, followed by smoking at 60–65 °C. The sausage loses between 15% and 25% of its weight during smoking. This high loss in weight is necessary to prevent the sausages from bursting during the retorting process. The non-cooked sausages are placed into glass containers, or jars, mostly in a ratio of 50:50, so that the volume in the jar is 50% sausage and 50% added water. The reason for the double addition of salt during the manufacture of the sausage now becomes obvious, as the salt leaches out of the product into the water to create a brine during and after retorting. By adding 4% salt to the sausage at the beginning, and having around 50% sausage present in the jar, the final salt content of the sausage will be 2%. The concentration of salt in the brine will be 2% as well.

Adding 4% salt increases the ionic strength substantially and, with the salt acting in conjunction with phosphates, large amounts of protein are solubilized. Having a high level of solubilized protein stabilizes the emulsion

during retorting and prevents fat separation. The end product is firmer than if only 2% salt (20 g per kilogram of total mass) is used, even if the sausages were packed with 2% brine. Nitrite must not be added at twice the normal amount, as nitrite will not leach out of the product during retorting and storage, and the residual nitrite would be beyond the legal limit.

When the ratio of sausage to water in the jar is different, e.g. 60% sausage and 40% water, the level of salt should be around 3.4% in order to end up with 2% in the final product. However, the ratio generally followed is 50:50 because this makes heat transfer during retorting more efficient. Having more product than water in the jar also increases the risk that the sausages might burst. Once the container has been filled and water added, the space between the product and the lid should be around 1 cm. The time between putting the sausages and water into the jars and subsequent heat treatment occurs should be as short as possible. This prevents the non-cooked sausages from absorbing the water prior to cooking and then bursting during retorting. Tap water, and not hot water, should be used to prevent the sausages from swelling before retorting. It is also important to make sure that the sausages fit the container vertically and are not too long, and that the smoke has covered the entire surface of each sausage. Smoke generates a second skin on the sausage, helping to prevent bursting during retorting.

Thermal treatment of frankfurters in brine generally follows the step-cooking method, and around 115 °C is the maximum temperature applied. Step retorting presents a gentler method of heat treatment, which is important because the product is quite delicate and applying temperatures in a gentler way reduces the risk of bursting. A counter-pressure has to be applied and tightly controlled during the retorting process to prevent the lid from bulging or the glass container from bursting. A counter-pressure of around 2.0 bar is applied for temperatures of 105–110 °C, and 2.5 bar is applied for 115–120 °C. A counter-pressure should also be applied during cooling while the temperature drops from its maximum level to below 100 °C.

Despite the advantages of the high-salting method, some frankfurter-in-brine products are produced by adding 2% salt and the necessary level of nitrite during the manufacture of the emulsion itself and using a 2% brine to fill the container.

## 12.6 Emulsifying in a grinder–emulsifier system

Large-volume production of cooked sausages is frequently carried out in a mixer–grinder system. In such a system, the all-in method is used. Frozen, semifrozen and/or chilled meat and fat materials are flaked, chipped or minced and placed in a large mixer, typically a paddle or ribbon mixer. If fat or skin emulsions are used, they are added to the mixer at the same time as all the other meat and fat materials. All the additives are mixed in; then the ice and water are introduced and mixing continues until all the ice and water is

properly absorbed and a tacky mass is obtained. Generally, the amount of ice and water introduced is between 20% and 35%, while the amount of lean meat varies greatly, between 20% and 40%. Fat is commonly present at between 22% and 30% and additives, or compounds of additives, are applied between 4% and 15%. A low-cost frankfurter would contain around 60% hard MDM, 5–10% skin emulsion, 15–20% water or ice and 10% additives, with proteins such as soy commonly being among the additives. The percentages of the different ingredients vary greatly, based on the expected cost structure and quality of the product being made.

The temperature of the meat and fat materials in conjunction with added water or ice is adjusted so that, after a certain period of mixing, generally between 5 and 10 min, the mixed and tacky mass has a temperature of around 2–6 °C. Mixing occasionally takes place under a vacuum. The mixed mass is then passed through an emulsifier, or colloid mill, and the high shearing forces experienced as the emulsion passes through the emulsifier activate high levels of protein. Fat is cut down to a size that is not visible in the final product after passing through the emulsifier and the sausage mass has a final temperature of around 8–12 °C. The temperature of the sausage mass before it passes through the emulsifier has a large effect on the temperature of the finished emulsion. It is not the case that, if the sausage mass is 1 °C above the set standard before it passes through the emulsifier, then the final temperature will also be 1 °C above the set final temperature. Generally, if the sausage mass goes into the emulsifier below the standard temperature, the increase in temperature during emulsification will be less than expected and smaller amounts of protein will be solubilized owing to reduced shearing forces, thus reducing the stability of the emulsion. On the other hand, if the sausage mass is at a higher temperature than the standard before emulsification, there will be large variances compared with the expected increase in temperature during emulsification. Elevated temperatures before emulsification result in higher than normal shearing forces, which cause a disproportional rise in temperature during emulsification. High shearing forces create a larger fat surface area, leading to reduced firmness and bite in the final product. The key to this process is once again to ensure that all materials are standardized for temperature, fat, water and protein content to achieve a consistent end product.

The advantage of a mixer–grinder system is that a large volume of sausage mass can be mixed at once and, after it has been emulsified, several filling or stuffing machines can be fed at the same time. Often, two large mixing machines can feed a single emulsifier so that the emulsifier operates continuously. The emulsified mass is pumped in pipes to the respective filling stations. This is a continuous process, the opposite to the batch production obtained using a bowl cutter. The system is easy to operate if all materials are fully standardized and a consistent product is assured without the need for skilled personnel.

A combination of bowl cutter and emulsifier is often used, and the sausage

mass is obtained in the first place either by the all-in method or occasionally by the lean-meat method. Whichever method is used, the sausage emulsion is cut to a temperature of around 2–6 °C in the bowl cutter before being passed through an emulsifier to achieve the desired final temperature. Using a combination of these two machines shortens the time that the sausage mass occupies the bowl cutter by around 50% and so productivity can be increased dramatically. The sausage mass must be at a predetermined and standardized temperature before being transferred from the bowl cutter into the emulsifier in order to obtain a consistent emulsion.

A water pipe is often connected to the bowl cutter or paddle mixer, and the exact amount of iced water can be added to the sausage mass by just turning a handle on and off. More advanced systems add a predetermined amount of ice and water at the required temperature to the bowl cutter or mixer by just pushing a button.

If materials such as mushrooms or green peppercorn, frequently sold in brine, are added as show pieces to the fine emulsion before filling, they must be washed with tap water and drained properly to remove the layer of acid present on such materials. If the acid is not removed, binding will be poor and the show materials will fall out of the product when it is sliced. The layer of acid on the surface of such materials prevents binding because it denatures protein. Mushrooms in brine also should be gently squeezed for a while after being washed in order to squeeze out some of the water present in mushrooms. Whole mushrooms in particular, stored in brine, contain much water and, if not squeezed, this water will not bind properly with the emulsion during thermal treatment, causing water separation to occur, especially if the product is filled into a waterproof casing.

To make the process more efficient, it is common practice for the people making the sausage mass to begin work earlier than those who complete the process by filling and cooking the product. This prevents staff from having to wait for the sausage mass to be prepared first before subsequent steps such as filling can take place. Alternatively, but not often practised, one or two batches of sausage mass are produced as the last batches of the day and cooled to around 4 °C using N<sub>2</sub> or carbon dioxide (CO<sub>2</sub>) before being unloaded from the bowl cutter into trolleys. Cooling must be rapid to reduce the risk of bacterial growth, because the raw sausage mass contains all the substrates for bacteria. The cooled sausage mass is then stored under chilled conditions and can be filled the next morning. Sausage mass that is going to be filled straight away after production should be stored at low temperatures and is commonly placed in the same room with the bowl cutter and filling machines. The temperature in those areas usually varies between 2 and 8 °C. Bacterial souring of the raw meat emulsion is particularly a problem in sausages such as bratwurst, which often contain fresh onions as onions are high in pyruvic acid. Onions often contain *Salmonella* spp. as well and products containing raw onion should never be stored uncooked overnight.

## 12.7 Filling

The sausage mass should be filled into the desired casings and heat treated as soon as possible after it is made. Souring can occur if there is a long time between procedures especially if the sausage mass is exposed to an elevated temperature or even room temperature. Souring makes the taste and flavour of the sausage unacceptable and impairs the binding in the emulsion owing to the drop in pH, which reduces WHC. The process of filling also affects the sausage mass mechanically, which is never advantageous.

Filling should take place at a moderate speed and the filling pipe, or filling horn, used should be as wide as possible for the casing being filled. Generally, the larger the diameter of the casing, the slower is the filling speed. Small-diameter and short sausages such as cocktail sausages can be filled at faster speeds because they consist only of a fine emulsion. Products containing show-meat must be filled more slowly. Using a wide filling horn allows the sausage mass to flow naturally, without being redirected. The filling horn should be as short as possible, because a long filling horn squeezes the sausage mass more during filling, which is not desirable. There should be no sharp edges or corners on the opening or inside the filling horn as they can interfere with the layer of protein covering fat particles, increasing the risk of fat and water separation during cooking.

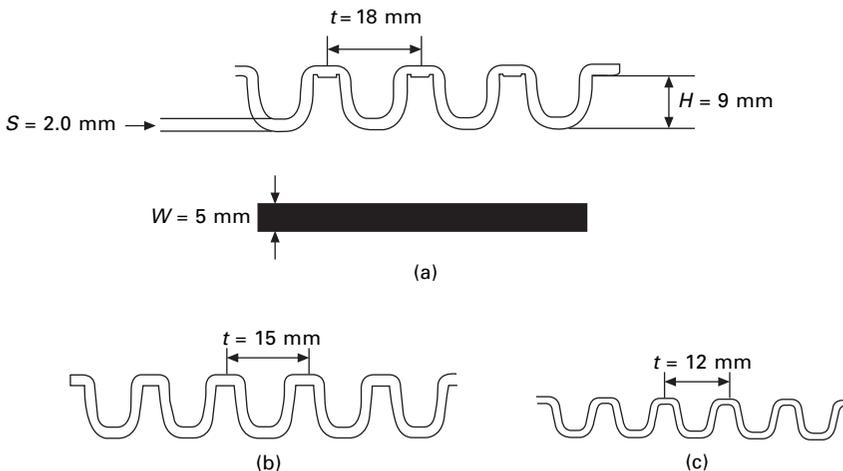
A vacuum should be applied during filling to prevent air pockets, as they affect the firmness, texture, colour and colour stability of the final product, as well as increasing the risk of fat and water separation within the air pockets themselves. The colour in air pockets quickly changes from red to green or grey during storage of the finished product. Applying a vacuum during emulsification as well as during filling results in a pore-free product with greater firmness, texture and bite. A vacuum filler by itself removes most, but not all, of the air present within the emulsion.

Cooked sausages are filled into natural casings such as sheep and hog casings, as well as large natural casings from cattle such as bungs. Most large-diameter cooked sausages are filled into waterproof casings (see Chapter 35, Section 35.4). Casings must not contain any residual water, which could be trapped during filling and would be present in the final product.

Casings have to be treated according to the manufacturers' recommendations before filling. Soaking times, temperature of the soaking water, filling speed and other specifications have to be followed in order to obtain all the benefits from the chosen casing. Tremendous improvements in filling have been made in the last couple of years, especially regarding speed and accuracy of filling. Modern filling machines can produce an extremely large number of portioned products such as cocktail sausage per minute and each and every one has exactly the same weight and length. Large-diameter products should be filled horizontally and straight, as any redirection of the sausage mass during filling applies mechanical forces, which increase the risk of fat and water separation.

All cooked sausages should be filled firmly into the respective casing. Filling the product too loosely affects the firmness of the finished product and could result in wrinkling. Filling products tightly into waterproof casings also helps to minimize the risk of fat or water separation during thermal treatment. Emulsified sausages with show-meat may also be filled into specialized non-waterproof casings, which can be smoked prior to moist thermal treatment. Large filling machines are commonly based on a rotor-like system, where the sausage mass comes down from the hopper and is moved in a circular way. Residual air is removed during this circular movement, before the sausage mass finally goes into the filling horn. Other filling machines operate a double-screw system, where two screws rotate in opposite directions to each other to move the sausage mass forwards. Small filling machines operate on a cylinder-type mechanism, where a cylinder pushes the sausage mass up or down into the filling horn. Most small filling machines cannot fill under a vacuum.

If an automatic, or semi-automatic, clipping machine is used, the clip must be placed correctly around the casing. The clip must fully cover the bundle of casing without cutting it. This can be a problem if a ready-made clip is placed too firmly on or around the casing, and especially if an 'endless' metal cord is used. In the latter, the clip is cut from the metal cord before being placed around the casing and this frequently results in sharp edges. If the casing is pierced even slightly, it will burst during cooking and this can result in large amounts of rework. Normally, working with automatic filling and clipping machines correctly hardly ever causes bursting. Figure 12.6 explains a clip and numbers connected to clips. The clip shown in Fig. 12.6(a) is an 18/9-5×2.0 clip which means that the width of the clip  $t = 18$  mm, the height of the clip  $H = 9$  mm, the width of the clip cord itself  $W = 5$  mm, and the strength of the clip  $S = 2.0$  mm. Clips with  $t = 15$  mm (Fig. 12.6(b)) and  $t = 12$  mm (Fig. 12.6(c)) are available as well.



**Fig. 12.6** Types of clip: (a)  $t = 18$  mm; (b)  $t = 15$  mm; (c)  $t = 12$  mm.

A solution containing ascorbic acid and water is frequently sprayed into the headspace during filling of canned emulsion products, before the lid is put on, to prevent the surface of the product from going green. Another way to avoid discolouration on the surface of the product which is going to be filled into a can and retorted is to remove air and oxygen (O<sub>2</sub>) from the headspace using steam just before the lid is applied. The lid should be placed on to the can under vacuum to remove O<sub>2</sub> entirely. Cans are usually retorted upside down because filling removes all the air from the bottom of the can. Turning the can upside down afterwards exposes the sausage mass to the air in the headspace, and it can become integrated into the sausage mass. Cans are also often lined with a non-stick foil or organic material to ensure easy removal of the product once retorted. An oil–water mixture is frequently sprayed into the can before filling, which also makes removal easy. Organic coatings are commonly solutions of resins in organic solvents and are either acid or sulphur resistant. Cans for meat products are predominantly coated inside with a sulphur-resistant layer, and cans for acidic materials, such as fruits, have an acid-resistant coating. The sulphur-resistant coating prevents the can from blackening on the inside as sulphur and other materials released from proteins during retorting would otherwise stain the metal.

## 12.8 Smoking, cooking and cooling

Large amounts of cooked sausages are smoked. Smoking has a profound impact on colour, taste, appearance, flavour, shelf life and bite in the final product (see Chapter 6, Section 6.11). Sausages in small-diameter sheep, hog or beef casings have to be conditioned before they are smoked so that the level of moisture and temperature on the surface of the product are consistent. This step is very important when large smoking chambers are used as it takes a considerable time to fill a large chamber with smoke trolleys. The products on the smoke trolleys that were put in the smoking chamber first often have different surface moisture levels from those that were placed in the chamber last. If smoking begins straight away, the differences in surface moisture will result in an uneven and irregular smoke colour. To prevent this, when the chamber is full, the products are showered for 1–2 min so that they all demonstrate the same level of surface moisture before smoking begins.

Another way to wet the product is to start the smoking programme with a reddening step at around 50–55 °C and a high RH, around 90%. During this period, the high temperatures and high levels of moisture speed up the formation of curing colour by wetting the surface, while temperatures below 55 °C do not denature proteins. The length of the reddening cycle depends on the diameter of the sausage. Large-diameter casings such as beef runners, with a diameter of around 32–40 mm, are reddened for around 30 min, while sausages in sheep casings (diameter, 20–22 mm) are reddened for around 15–20 min.

Once consistent surface conditions have been obtained and reddening is completed, the next step in the smoking process is drying. Drying commonly takes place at around 60–65 °C and in an RH between 20% and 40%, until the surface of the product to be smoked is dry but not dried out. Overdried products do not take up smoke well because the surface is too dry to absorb smoke particles. A rule of thumb is that, once drying is completed, a natural casing should ‘feel like human skin’, elastic, soft and slightly moist. Underdrying results in a dull and often uneven or streaky smoke colour, as the level of moisture on the surface of the product is too high for smoke particles to be absorbed evenly. The drying effect is closely related to air velocity, and air is blown through the chamber during drying. Airflow conditions must be the same throughout the chamber to ensure that products are dried evenly, and the smoking chamber must not be overfilled as this can affect airflow. The next step is smoking, which takes place at around 60–70 °C and an RH of 40–60%. The level of moisture during smoking varies depending on the desired colour. Higher levels of moisture during smoking result in a darker smoke colour. The length of the smoking cycle depends on the desired colour and the desired intensity of smoke flavour as well as the amount of smoke generated by the machine itself. Generally, sausages such as frankfurters in sheep casings are smoked for around 15–20 min, followed by a short drying stage once smoking is completed in order to fix the colour on the product even more before moist thermal treatment starts. Occasionally, two shorter smoking cycles are carried out instead of one long smoking cycle, with a short drying stage of around 5 min between the two smoking cycles. The process of smoking therefore could consist of 10 min smoking, 5 min drying and another 10 min of smoking.

As a general rule, smoking begins after the curing colour is fully developed, because some of the substances present in smoke, such as phenols and other organic acids, have a negative effect on the development of curing colour.

If collagen or cellulose casings are used, the manufacturer will provide specific instructions regarding the reddening, drying and smoking times required. The process normally does not differ significantly from that for products in natural casings. Conditioning at high RH for around 5–10 min is often the first step, to create the same surface conditions on all products to be smoked, as before. The sausages are then dried at a low RH and temperatures around 55–60 °C for around 5–10 min before being smoked at 60–65 °C for around 15–25 min at low RH. The smoking cycle is frequently divided into two steps with a short period of drying in between to fix the colour, or there is a drying period of around 10 min at the end of an uninterrupted smoking cycle. Moist thermal treatment takes place afterwards.

Sausages in natural or collagen casings that will be retorted in glass containers are dried and smoked so that they lose around 20–30% in weight. The severe drying and occasionally severe smoking creates a hard ring around the sausage, increasing bite and snap in the retorted product. The high loss

in weight is necessary to prevent bursting during retorting. The products normally take up water again, during retorting, storage and reheating, as such products are commonly consumed warm and are usually reheated using steam or hot water.

Smoking using liquid smoke takes place after conditioning and drying at 55–60 °C for 10–15 min, or as long as necessary to obtain a dry surface with an RH level of 20–40%. Liquid smoke is atomized for around 10–15 min under a low RH, with the chamber closed off and all dampers and valves closed. After around 5 min, there is a short drying stage of around 5–10 min at 65 °C, and the exhaust valves are opened again before drying. The cycle of atomization, standing and drying is repeated, generally twice, before the final moist heat treatment takes place. When liquid or conventional smoke is applied on products such as skinless frankfurters which are filled into cellulose casings with the casing being removed afterwards, smoke should penetrate at least 1 mm into the product to form the hard surface ring. If the layer of smoke is very thin, the colour on the actual product fades in 1–2 days after the casing has been removed, because most of the smoke colour was present on the casing. It is vital that correct concentrations of liquid smoke are introduced into the smoking chamber in order to obtain a consistent and lasting smoke colour. Products which are put through a bath of liquid smoke can cause the liquid smoke solution to foam. Antifoaming agents are used to prevent this, and some manufacturers incorporate antifoaming agents in their liquid smoke products.

In the USA, most customers prefer light-coloured products and therefore sausages in natural casings are usually dried for a prolonged period because a dry surface does not take up as much smoke as a moist surface. In other parts of the world, such as South Africa and some South American countries, darker-coloured products are preferred and the drying process is quite short.

Smoked products are generally cooked by steaming. It is important to have sufficient air circulation, or convection, in the cooking chamber when cooking by steam. Cooking in a water bath is more effective than steaming, as the hot water represents an RH of 100% but steam never reaches the same level of RH. Theoretically, all smoked products can be cooked in a water bath, but additional handling is required, firstly to place the mostly hung smoked product in the water bath, and then to remove them afterwards. Hung products that are steamed remain hung during all processing steps and no double handling is required.

During cooking, the layer of activated protein, which contains added water and covering fat globules, is denatured. This immobilizes water in the layer of protein and stabilizes the fat globules in a three-dimensional matrix. Cooking takes place at temperatures between 74 and 80 °C. Temperatures below 74 °C significantly prolong the period of time until the desired core temperature, or  $F_{70}$  value, is obtained. Temperatures above 80 °C significantly increase the risk of fat and water separation. A core temperature between 70

and 72 °C is commonly aimed for. This core temperature not only is beneficial from a microbiological point of view but also stabilizes the curing colour fully. A temperature range of 65–68 °C is not safe microbiologically unless the core temperature is held at 68 °C for a prolonged period of time, at least 20–25 min. Core temperatures of 65–68 °C are insufficient to stabilize the curing colour fully, because myoglobin is only completely denatured at 70 °C. The colour of undercooked products fades over time because the nitrosomyoglobin is insufficiently denatured and NO separates from it, leaving myoglobin which is susceptible to oxidation.

Small-diameter sausages are usually steamed at 76–78 °C for around 20 min; larger products are steamed for longer, until a core temperature of 70–72 °C is obtained. Cooking small-diameter products based on a set core temperature is common practice, but thermal treatment of large-diameter products is also frequently based on reaching predetermined  $F_{70}$  values. Care should be taken if a set cooking programme for a large-diameter product is changed to apply higher cooking temperatures based on a certain target core temperature. Raising the cooking temperature means that the required core temperature will be reached earlier, thus reducing the amount of time during which bacteria will be killed by the heat. Thus the target core temperature should be slightly higher than that for a cooking programme based on a lower cooking temperature.

Products consisting either of a fine emulsion only or a mix of fine emulsion and show-meat are commonly filled in large-diameter waterproof casings and cooked either with steam or in a water bath. Temperatures applied vary between 76 and 80 °C, and a target core temperature of 70 °C is typical. Large-scale production of large-diameter cooked sausages in waterproof and non-waterproof casings is also regularly based on reaching a predetermined  $F_{70}$  value, and core temperatures between 68 and 70 °C are held for a certain period of time to obtain the required value (see Chapter 40, Section 40.2).  $F_{70}$  values commonly aimed for in large products vary between 40 and 60 min, based on a reference temperature of 70 °C, but can be higher. Generally, large-diameter cooked sausages are cooked to a slightly lower core temperature than small sausages, as the accumulation of lethal effects secures shelf life. Products containing high levels of starch or other cereal-based fillers expand during thermal treatment and the tightness of filling, especially for waterproof casings, should be chosen with care to prevent bursting during cooking. Poultry products such as chicken hot dogs are commonly cooked to a higher core temperature because food standards in some countries specifically ask for core temperatures as high as 75–76 °C. The *Salmonella* bacteria are more common in poultry than in other types of meat and higher core temperatures help to ensure that such products are safe.

A rule of thumb is that the cooking temperature applied is 6–10 °C higher than the target core temperature. For example, if a core temperature of 70 °C is required, the product is thermally treated at 76–80 °C. A difference of 6–10 °C ensures a fairly quick rise in core temperature, which is important

because the product should pass as quickly as possible through the 7–55 °C temperature range, to avoid excess bacterial growth.

Cooking for sausages normally takes place at constant temperature. Alternative cooking methods, such as step cooking, or  $\Delta T$  cooking, are seldom used (Chapter 8, Section 8.4.7).

Cooking, or more accurately retorting, of canned products such as spam, is generally based on  $F_{121.1}$  values to achieve a specified shelf life under non-refrigerated storage conditions. Generally,  $F_{121.1}$  values of between 8 and 12 min are obtained. A counter-pressure must be applied properly during retorting and cooling to prevent the lid from bulging or the container from bursting.

Once the target core temperature or  $F$  value is reached, the products are cooled. Sausages in natural casings are generally showered with cold water for around 15–30 min, depending on the diameter. The water must be cold; tap water in tropical countries is commonly stored in tanks in sunlight and could be at 35 °C, or more, resulting in low cooling capacity. Only cold water will absorb, or remove, the internal heat from the product, especially products in natural casings. If the product is not showered sufficiently with cold water, it will become wrinkled during storage because the warm sausage mass will continue to shrink with the casing having insufficient moisture to shrink with the product at the same time. Wrinkled sausages do not appeal to the consumer and can also result from the combination of loose filling and insufficient showering. After they have been showered, the surface of sausages in natural casings should not feel hot or warm any longer.

The shelf life of sausages in natural casings can be improved by using a solution made out of water and around 2–3% vinegar and 7–8% salt. This solution is applied for around 2–4 min at the end of the showering period and reduces the bacteria count of the surface because acetic acid (in vinegar) and salt are both growth inhibitors. The level of vinegar and salt in the showering solution is calculated so that it does not affect the taste of the product.

Different types of waterproof casing require different showering regimes to prevent wrinkling or splitting, although some types of waterproof casing do not need to be showered at all. However, even sausages in this type of casing are commonly showered for a short while to reduce the temperature of the sausage mass quickly after thermal treatment for microbiological reasons. Showering is not only necessary for casings which need to be showered to prevent bacterial growth but is also important for shrinking of the casing itself so that a tight-fitting and wrinkle-free product is obtained once cooling is completed. The process of showering provides moisture to the shrinking casing which follows shrinkage of the product itself during cooling. Proper shrinking of the casing is also important to reduce the risk of water separation in the finished product.

Showering, as described in Chapter 8, Section 8.4.9, should take place in intervals, because interval-showering has a greater cooling effect than continuous showering, and the amount of water used is reduced by 50%. The

showering water sometimes is recycled, which is extremely cost effective in the long run. If the cooked sausage is cooled in a water bath, the water must be kept running to introduce cold water continuously into the cooling tank, or ice must be added occasionally; otherwise the temperature of the cooling water will rise and the cooling effect decreases. There is also a microbiological risk if running water is not used, because the increasing warmth favours bacterial growth, especially if natural casings are used. Cooling water, to some degree, is always contaminated, and bacteria can cause shorter shelf life and formation of purge and slime.

All sausages should be cooled quickly to an internal temperature below 10 °C as surviving spore formers could germinate at temperatures above 10 °C. Once properly showered, the sausages are cooled quickly, usually in a blast chiller, down to a temperature below 4 °C to prevent bacterial growth. Blast chillers normally operate at around 0–2 °C, and high airflow is generated to aid the cooling process. Blast chilling is a very effective way of reducing the internal temperature quickly. Products should not be cooled in a freezer because water will turn into ice, particularly in the surface layers of the product. Ice formation increases the risk of purge and softens texture and bite because the ice crystals destroy the three-dimensional matrix of denatured protein covering the fat globules.

Several countries have regulations on how quickly products have to be cooled, demanding certain core temperatures after certain periods of time. Cooling requirements are most common for large-diameter products.

## 12.9 Slicing, packing and storage

After cooling, products in waterproof casings that are not going to be cut or sliced are stored between –1 and 4 °C. Although 4 °C is considered safe from a microbiological perspective, storage temperatures are most commonly below 2 °C because for every single degree below 4 °C the shelf life is extended greatly. Waterproof casings often act as the packaging as well and no secondary packaging is needed, which saves on packaging and labour costs.

Portioned cooked sausages are commonly vacuum packed, and a full vacuum, –0.98 bar or more, has to be applied before the bag is sealed. The sealing process must not cut the bag and care must be taken to ensure that none of the product is placed across the seal as this would allow air to penetrate into the bag. Vacuum packing eliminates the growth of aerobic spoilage bacteria such as *Pseudomonas* spp. and, in combination with low storage temperatures between –1 and 2 °C, improves the shelf life of the product. Vacuum-packed products are also frequently packed in vacuum-shrink bags and then placed in hot water, at 90 °C, for 2–4 s, i.e. the PPP process; even this short immersion in hot water improves shelf life by reducing the bacteria count on the surface of the product. PPP also shrinks the bag tightly on to the product, which is more visually attractive. PPP is excellent

for products packed in a single layer, such as frankfurters, where the entire surface area of the product comes into contact with the hot water during dipping.

Portioned products can also be packed in a modified atmosphere. The packaging generally contains 30–40% CO<sub>2</sub> and therefore 60–70% N<sub>2</sub>. As N<sub>2</sub> is an inert gas, it replaces O<sub>2</sub> and the final level of O<sub>2</sub> in the packaging should be less than 0.6%. CO<sub>2</sub> forms carbonic acid on the surface of the packed product, which improves shelf life. In addition, CO<sub>2</sub> also interferes with the metabolic activity of countless pathogens thus increasing shelf life once more. If 100% CO<sub>2</sub> is introduced by accident, it can cause the product to taste slightly sour. The CO<sub>2</sub> also enters the product because it is highly soluble at low temperatures, it then expands dramatically on reheating, causing bursting of the product. In addition, if the modified-atmosphere packing uses only CO<sub>2</sub>, the product will appear vacuum packed because the high solubility of CO<sub>2</sub> causes ‘shrinking’ of the packaging material. Products such as frankfurters are generally packed on the same day as production, which shortens the time during which recontamination could take place and excess loss in weight is avoided as well. The formation of condensation must be avoided during packaging (see Chapter 4, Section 4.12) because any freely available surface water on the product can be used by bacteria for growth, even if the product is vacuum packed. Condensation can result in a slimy purge and discolouration, mostly greening. Milkiness in purge tends to be the accumulation of *Lactobacillus* cells rather than a metabolic by-product of the bacteria.

Condensation must also be avoided during slicing, for the same reasons. Hygiene in the slicing area, in the equipment and among staff must be extremely high and continuously checked. The basic message is that every single bacterium introduced during slicing shortens shelf life. Cooked sausages are high in water content ( $A_w$ ) and are very perishable. Poor slicing and packing hygiene are almost a guarantee for countless problems afterwards, in shelf life, colour, formation of purge and slime, flavour and so on. These problems are multiplied if incorrectly treated sliced products are stored at high temperatures.

Sliced products are commonly vacuum packed or packed in vacuum-shrink bags (see above). It is better to pack sliced products as if they were roof shingles than to stack the slices, as this allows more surface area in contact with hot water during dipping after packing (PPP), thus improving shelf life (see Chapter 8, Section 8.4.11). Cooked sausages should not be frozen as the formation of ice crystals during the freezing process damages the protein fat structure, resulting in a soft product after thawing and a high degree of purge. Freezing and thawing can be carried out successfully to a certain degree if around 2–3% of freeze-thaw-stable modified starch is added during production, and the product is thawed under chilled conditions, between 2 and 4 °C. If the product is frozen, then this should be carried out very quickly using cryogenic gases such as N<sub>2</sub> or CO<sub>2</sub> as fast freezing causes

significantly less damage to the product than slow freezing at temperatures around  $-18\text{ }^{\circ}\text{C}$ . Portioned fast-frozen products such as frankfurters should be placed in hot water for reheating and not thawed out first (see Chapter 4, Section 4.7), whilst slow-frozen products should be thawed slowly prior to being placed in hot water. However, a frozen and thawed product will never display the same eating qualities as a cooked sausage that has not been frozen.

Heterofermentative *Lactobacillus* spp. that survive the production and packing processes cause gassing, or the formation of  $\text{CO}_2$ , in packed products. *Lactobacillus* spp. are facultative anaerobes, which mean that they can live with or without  $\text{O}_2$ , and packages where *Lactobacillus* spp. are highly active blow up like balloons. Heating the product to  $70\text{ }^{\circ}\text{C}$  deactivates *Lactobacillus* spp. Greening inside a cooked sausage is frequently caused by *Lactobacillus viridescens*, which produces hydrogen peroxide ( $\text{H}_2\text{O}_2$ ), a strong oxidizing agent. Microbiological greening is differentiated from chemical or metallic greening by the fact that it spreads across the product. Greening is occasionally seen in the outside layers of a cooked sausage and is most likely a combination of oxidation and elevated numbers of greening bacteria. Surface greening of cooked sausage and other meat products is also often caused by various heterofermentative *Lactobacillus* spp., especially non-packed products, and discolouration starts to appear after 3–5 days.

All products, portioned, non-sliced, sliced, vacuum packed, shrink vacuum packed, modified atmosphere packed or packed in any other way, should be stored at temperatures between  $-1$  and  $4\text{ }^{\circ}\text{C}$  and a maximum temperature of  $2\text{ }^{\circ}\text{C}$  is preferred. Products should also be stored away from exposure to light, as photolysis causes the curing colour to fade over time.

## 12.10 Summary of critical production issues

- 1 Raw materials should have a low bacteria count of  $10^2$ – $10^4$  per gram of product and a pH of at least 5.7.
- 2 The fat used must not be rancid.
- 3 Frozen or semifrozen meat and fat material can be processed without problems and the amount of ice, or water, added to the emulsion should be adjusted to obtain the correct temperatures in the sausage mass.
- 4 The water and/or ice used must be of drinking or food quality.
- 5 Premincing of meat and fat materials is recommended as this creates a larger surface area and preminced fat does not need to be cut in the cutter as intensively as non-minced fat.
- 6 Functional additives such as phosphate, salt and protein are added at the beginning of the cutting or mixing process.
- 7 The final temperature of the emulsified sausage mass is between 8 and  $14\text{ }^{\circ}\text{C}$  depending on the system used for emulsification and can be as low as  $2\text{ }^{\circ}\text{C}$  if  $\text{N}_2$  is used during processing.

- 8 Cutting or mixing under a vacuum is advantageous.
- 9 Filling is best carried out under a vacuum and using the largest filling horn possible.
- 10 Products should be filled tight and the filling speed for large-diameter products should be moderate.
- 11 Thermal treatment is usually carried out by cooking at 74–80 °C to obtain the target core temperature (around 70–72 °C) or  $F_{70}$  value.
- 12 The product must be showered after cooking to reduce the internal temperature quickly and to avoid wrinkling.
- 13 High hygiene levels are essential during slicing and packing, together with measures to prevent condensation.
- 14 The finished product should be stored between –1 and 2 °C and exposure to light should be kept to a minimum.

## 13

# Typical cooked sausage products from around the world

### 13.1 Frankfurters (Austria and Germany)

Frankfurters in Austria and Germany are high-quality products and made with around 40–45% lean meat, typically a mixture of beef and pork. Pork fat from all cuts is processed as well as jowls, and ice (and water) accounts for around 22–26% of the total mass. The fat content in the final product is around 24–28%. These high-quality sausages have added phosphates, salt (around 1.8%), nitrite, colour enhancer and spices. Binders (or fillers) such as cereal binder or starch are either not added at all or only to a maximum of around 2%. The product is commonly produced using the lean-meat method and is filled into natural sheep casings of 18–22 mm diameter. The filled product is reddened at around 55 °C in an RH of 80–90% for 10–15 min, dried at 60–65 °C for 15–20 minutes in a low RH, and then smoked for 10–15 minutes at 65 °C and an RH of 40–60%. The frankfurters are then often dried for 2–3 min at 60–65 °C after smoking to fix the smoke colour. Cooking with steam or in a hot-water bath at 74–78 °C up to a target internal temperature of 70–72 °C completes the process. The frankfurters are then showered for 15–20 min, placed in a blast chiller or chiller and then vacuum packed or modified atmosphere packed. Frankfurters are consumed hot and are reheated by placing them in hot water for 15–20 min. The relatively high levels of meat and moderate levels of fat and water create a firm texture, resulting in the desired bite, or snap.

### 13.2 Frankfurters (Philippines)

Two different qualities of frankfurters are made in the Philippines. The high-quality product contains around 48% lean forequarter beef, 95% CL grade,

or Indian buffalo, 22–25% pork back fat or any other available fat (including beef fat), 16–18% water or ice, 1–1.5 soy protein and around 10% of other additives such as phosphates, salt, nitrite, spices and fillers. The low-cost frankfurters are made from 20–22% lean forequarter beef, 10% fat, around 20% water, around 5% powdered TVP, 0.5–1% soy isolate, 10% additives including starch and 35% water. MDM is occasionally used as well. Quite high levels of sugar are used and the sausage often tastes slightly sweet as a result. Salt is present at around 1.5% in the final product. The emulsion is generally produced using the all-in method and a final temperature of around 12–14 °C is aimed for. Large producers also work with the mixer–emulsifier system. The sausage mass is filled into cellulose casings and dried at 60–65 °C and then smoked and cooked with steam to a core temperature of 70–72 °C. Natural smoke and liquid smoke are used. The vast majority of frankfurters in the Philippines are sold with the casing or skin on, even though the casing is not consumed and must be removed before the sausage is eaten.

### 13.3 Frankfurters (South Africa)

Frankfurters made in South Africa are a low-cost product and the meat portion varies between 15% and 35%, with MDM often being the only source of meat. The quality of frankfurters made with 100% MDM depends largely on the quality of the MDM itself. Fatty trimmings from beef or mutton are also processed together with high levels of skin and fat emulsions (5–15%). Added water is normally high, up to 35–40%, and additives, including fillers and high levels of soy protein, are used to obtain some degree of bite. Soy protein can be present at levels up to 12%. The amount of meat, including MDM, skin and/or fat emulsions, and water in a recipe depends largely on the desired cost structure of the product, taking account of the fact that a large proportion of the population cannot afford high-quality products. Egg proteins are also used because they form a solid gel, which contributes to firmness and texture.

Colourings such as fermented rice, carmine or allura red are also frequently introduced because there is little myoglobin but high levels of non-colouring materials such as binders and water. The emulsion is usually made using the all-in method, either in a bowl cutter alone or using a bowl cutter followed by an emulsifier. Large-scale production is also carried out using a mixer–emulsifier system. The emulsion is filled into collagen casings, or cellulose casings if a skinless product is required. Smoking using natural smoke follows a very similar pattern to that described in Section 13.1. Liquid smoke is frequently introduced into the emulsion to give a smoke-flavoured product without smoking by products which are just cooked after filling. The filled sausages are also often dipped in a bath of liquid smoke, followed by a short drying stage at 65–70 °C in a low RH to fix the colour on the product. The

hung product is generally steamed at 76–80 °C until a core temperature of 70–72 °C is reached. Proper showering, cooling and vacuum packing completes the process before the product is stored at around 0 °C.

Skinless sausages such as frankfurters and hot dogs are filled into cellulose casings and then peeled after being cooked and showered using a peeling machine. Such a machine can operate in two different ways. Longer sausages such as frankfurters pass through two counter-rotating parts which are arranged horizontally; one side has a tiny knife, which cuts the casing. The vacuum present in the section where cutting takes place removes the casing from the sausage. Short sausages, such as cocktail sausages (around 2–3 cm in length) cannot be peeled this way because the sausage is too short to pass through the horizontal machine. For short sausages, the counter-rotating parts are placed vertically, or on top of each other, but otherwise the process is the same.

For both methods of peeling, the sausage is soaked in warm water for a short while before being passed through the peeling machine, in case the product has been standing in the chiller for a prolonged period of time and the surface has dried out. Soaking for a short while, just a few seconds, softens up the surface of the sausage itself and also makes the casing softer, making peeling easier. High levels of fat, collagen-rich meat material, skin emulsion and starch within the product decrease the peelability of skinless sausages. On the other hand, acids present in smoke or liquid smoke make them easier to peel, because they form a second ‘skin’ as they denature the surface protein.

### **13.4 Frankfurters (Malaysia)**

Frankfurters made in Malaysia contain around 50–65% chicken MDM and 10–20% water and ice. Additives applied are phosphates, nitrite, spices and salt with salt being present at 1–1.2% in the finished product. 1–3% soy isolate as well as 3–8% starch are also applied. Fermented rice is frequently used as colouring. The emulsion is often produced using the all-in method by utilizing a combination of bowl cutter and emulsifier or the mixer–emulsifier system. The finished emulsion is filled into cellulose casings, smoked and cooked before being peeled. The peeled product is vacuum packed with ten pieces being placed in a bag and stored frozen.

### **13.5 Chicken sausage with oil**

Chicken sausages such as hot dogs or frankfurters are commonly made from a mixture of chicken thigh and breast meat. If a white non-cured product is desired, then most of the meat used must be chicken breast, which adds

considerable cost. Cured sausages, where a pink–red curing colour is desired, can contain thigh meat and some MDM meat besides breast meat. Low-cost products are produced with thigh and MDM meat only.

A medium-quality chicken sausage produced with oil would contain 10% chicken breast meat, 30% chicken thigh meat, 5–10% MDM, around 20–22% chilled vegetable oil, around 25% water and ice and around 6–8% powdered additives such as phosphates, salt, spices, nitrite and colour enhancer (in cured products) and fillers such as starch. Starch is white and therefore helps to keep the colour of the finished product light. The amount of salt is generally fairly low, around 14–16 g per kilogram of total mass, because chicken sausages have a light, healthy and easy-to-digest image.

The process of making the emulsion is described in Chapter 12, Section 12.5.5, and it is usually filled into collagen casings of around 22–26 mm diameter. After filling, the product is steamed at 76–80 °C until a core temperature of 70 °C is reached; it is then showered, cooled in a blast chiller, placed in a chiller and vacuum packed. Occasionally, the filled product is smoked prior to moist heat treatment or smoke flavour is added to the emulsion to obtain a frankfurter-type product.

### 13.6 Cooked bratwurst

A cooked bratwurst consists of a fine emulsion with visible particles of meat and fat as show-meat. Bratwurst is usually not cured, but cooked bratwurst made using an emulsion as the base is a cured product and contains nitrite. The composition of the emulsion varies greatly, and a medium-quality emulsion would contain around 40–45% meat, 26–28% fat and 22–25% water and ice. Additives used include phosphates, salt (around 18 g per kilogram of product), nitrite and colour enhancer (ascorbic acid or ascorbate), spices and frequently starch at around 1–3% based on the total. The emulsion itself is either made following the lean-meat method or the all-in method, and machines such as bowl cutters and/or emulsifiers are used.

Precured minced meat and fat particles are gently mixed into the emulsion, and spices are generally added to the fine emulsion only at a level covering both the fine emulsion and the show-meat. The total sausage mass consists of 60–80% emulsion and 20–40% show-meat. If the minced meat mixed in is not cured, salt and nitrite are added to the emulsion to ensure the correct levels in the finished product. Precured show-meat is the preferred option and results in a stronger and more lasting curing colour. The mixed sausage mass is filled into hog casings of 28–34 mm diameter, and thermally treated with steam or in a bath of hot water at 76–80 °C until a core temperature of 70 °C is reached. The cooked product is showered before being placed in the chiller. Vacuum packing commonly completes the process and the product is very often enjoyed grilled on a barbecue.

### 13.7 Hunter sausage

Hunter sausage is a cold-cut sausage filled into waterproof casings with a diameter between 80 and 100 mm and has around 30% visible meat and fat particles in a fine emulsion. Lean meat accounts for around 70% of the visible meat and fat particles and precured pork trimmings of 75–80% CL grade are frequently used as show-meat. The precured meat and fat particles are minced with a 6–8 mm blade before being added to the sausage mass, which is produced mostly following the lean-meat method. As in Section 13.6, the emulsion is of a very similar composition to the additives applied. Green peppercorns are often added to the sausage mass during mixing, after being washed with cold water to remove the brine that they have been stored in. The mixed mass is filled under vacuum and thermally treated with steam or in a hot-water bath at 76–80 °C until a core temperature of 70 °C is reached. After proper cooling, the product is sold in delicatessens or sliced and vacuum packed.

### 13.8 Beer ham (Germany)

For beer ham, the fine emulsion (see Section 13.6) is mixed with large lean cured pieces of pork, which have either been cut into cubes of around 3 cm × 3 cm or passed through a kidney blade. Occasionally, the chunks of lean meat (95% CL grade) are passed through the mincer worm to tear the lean muscle tissue apart. The lean meat is commonly tumbled with phosphates, salt, nitrite, colour enhancer (ascorbate) and around 5–10% brine. The brine contains phosphates at 5 g per kilogram of meat, salt at around 18–20 g per kilogram of meat and nitrite at around 150–250 ppm per kilogram of meat. The brine is prepared by fully dissolving the phosphates in ice-cold water and then adding the salt and nitrite. The meat is tumbled under full vacuum for around 1500–2000 rev and a tacky meat mass is obtained, which is mixed together with the fine emulsion gently in the mixing machines so that the pieces remain large. The final product contains around 30–40% fine emulsion and 60–70% of lean precured and tumbled meat.

The finished product contains around 1.8% salt. As the tumbled meat contains all the salt, nitrite and colour enhancer necessary, these do not need to be added to the emulsion. Generally, only the spices are added to the emulsion covering both the fine emulsion and the show-meat to avoid adding spices to the tumbler or mixer. Care must be taken to ensure that the tumbled meat mass has a temperature similar to the fine emulsion before the two are mixed, because large differences in temperature result in water separation during thermal treatment. The difference between the temperature of the tumbled meat and that of the emulsion should not exceed 4–6 °C. Generally, the tumbled pieces of meat have a temperature around 4–6 °C after tumbling and, if mixed for a short while in the paddle mixer, the temperature increases

to around 8 °C. If the temperature of the emulsion is around 10–14 °C when the emulsion is added, this creates strong binding between the activated surface protein from the tumbled meat and protein in the emulsion itself, preventing water separation. For example, mixing tumbled meat showing a temperature in the range from 0–2 to 4 °C with an emulsion showing a temperature of 14 °C will result in water separation.

Applying a vacuum during mixing helps to remove trapped air, improving the texture and also reducing the risk of water separation. The mixed product is filled into waterproof casings of 90–120 mm diameter and cooked with steam, or in hot-water bath, at around 76–80 °C until a core temperature of 70 °C is obtained. After cooling, the product is commonly sliced and vacuum packed or sold in a whole piece to delicatessens to be sliced on demand.

### **13.9 Luncheon meat (Australia)**

Luncheon meat is widely consumed in Australia, usually eaten in sandwiches. There is no show-meat in the emulsion and fatty beef and mutton trimmings are frequently used. Generally speaking, luncheon meat is a low-cost cold-cut product and is always filled into a waterproof casing of around 80 mm diameter. Commonly, the all-in method is used, in a bowl cutter or using a combination of bowl cutter and emulsifier. The finished emulsion contains around 30–35% lean meat, 20–24% fat, 30–35% water and ice and 5–10% powdered additives, including phosphates, nitrite, ascorbate, soy protein and fillers such as starch and cereal binder. The finished product contains 1.8–2.0% salt. After emulsification and filling, the product is cooked in a hot-water bath or with steam at 76–80 °C until a core temperature of 70 °C is reached. The chilled product is generally sliced and vacuum packed or sold to the end consumer in a whole piece weighing between 300 and 500 g.

### **13.10 Weisswurst (Bavarian white sausage) (Germany)**

Weisswurst is a typical Bavarian delicacy and is made without nitrite. Pork and veal meat are used, together with pork fat. Weisswurst contains 35–40% lean meat, 20–24% fat and around 30–35% water and ice. Additives used include phosphates, salt (around 1.6–1.8%) and spices. Fillers are not normally used. The product is made following the fat method (see Chapter 12, Section 12.5.4) in order to obtain a soft and sloppy texture. Cooked and finely minced meat, obtained from veal heads which have been cooked and deboned, are added and mixed in gently at the end of the cutting process. Fresh parsley is cut into the emulsion in the final stages of cutting so that it is visible in the finished product, and a touch of lemon is frequently added as well. Weisswurst is filled into hog casings of 26–32 mm diameter and cooked with moist heat,

either steam or in a hot-water bath, at 74–78 °C until a core temperature of 70 °C is reached. The product is then showered and chilled before being vacuum packed. Some is sold unpacked to delicatessens. Weisswurst is reheated in hot water and consumed hot.

### 13.11 Mortadella (Italy)

Mortadella is a traditional Italian delicacy from Bologna. It is light pink in colour and the fine sausage mass has visible fat cubes distributed evenly throughout. Traditional mortadella is a shelf-stable product and no refrigeration is required. Original Mortadella is made from meat and fat from pork only and also contains, depending on the quality of the product, pork rind emulsion and/or cooked tripe. Tripe and pork stomachs are used for reasons of cost and taste, because tripe not only is cheap but also contributes to the flavour in a unique way. A traditional high-quality mortadella contains around 35% pork trimmings (shoulder) (90% CL grade), pork trimmings (85% CL grade), 15% pork belly, 10% tripe and 20% visible cubes (around 1 cm × 1 cm) of pork neck fat. If no tripe is available, then 35% belly meat is used. Traditional mortadella is made in a mincer–mixer system. Only around 4–5% water is added. Caseinate or dried milk powder is sometimes used at 2–5%, and the additives include nitrite. More economic recipes contain around 6–15% rind emulsion, less lean shoulder meat and up to 25% visible pork back fat. Around 10% water is added in cheaper recipes, and the product is commonly made in the bowl cutter. The spices used in mortadella include nutmeg, cinnamon, cloves, pepper and a touch of coriander.

The process of producing traditional mortadella starts with mincing or flaking tempered meat and fat (and tripe) at around –5 °C and then placing them both in a mixer. The meat and fat are mixed and then minced with a 12–14 mm blade. The coarsely minced mass is then minced again with a very fine blade, 0.8–0.9 mm, and the finely minced mass is returned to the mixer again. Salt, water, nitrite, spices and all other additives are added, and everything mixed well until a tacky mass is obtained. Occasionally, materials such as spices, salt, nitrite and water are added to the coarsely minced materials and mixed well before being minced with the 0.8–0.9 mm blade. This avoids the addition of powdered materials to a very finely minced meat mass. Blanched (90 °C for around 2–3 min) and drained fat cubes are then mixed into the finely minced mass.

The sausage mass is filled into large fibrous or cellulose casings and commonly placed in a net (depending on the size and weight). It is then baked (dry heat) at 82–85 °C in a low RH until a core temperature of 74–76 °C is reached. Traditional mortadella is not smoked, although some modern recipes do add a touch of smoke. The loss in weight during baking is around 15% and the  $A_w$  in the finished product is around 0.93, which restricts the growth of bacteria such as *Salmonella* spp. The high core temperature during

baking also destroys bacteria very effectively, especially those which might otherwise survive and grow at the low  $A_w$ , such as *Staphylococcus aureus*. The final product contains around 2.2–2.4% salt, which is quite high, thus lowering the  $A_w$  and improving stability. The combination of effectively killing all vegetative bacteria, reducing the  $A_w$  below 0.95, and having high levels of salt and other water-binding agents makes a traditional mortadella shelf stable.

Many different qualities of mortadella are produced, and much of it has very little resemblance to the traditional product. Commonly, a fairly low-cost fine emulsion is made using the all-in method and blanched cubes of fat are mixed into the emulsion. The finished emulsion is then generally filled into large fibrous casings and dried at 60–65 °C in a low RH before being smoked for a short while at around 70 °C. The product is then steamed at 78–80 °C until a core temperature of 70 °C is reached. Heat treatment is sometimes carried out in stages, first steaming until the core temperature reaches 65 °C and then baking at around 85 °C to raise the core temperature to 70 °C, which results in a stronger colour and flavour. These types of mortadella are not shelf stable and must be stored under refrigeration. Low-cost mortadella may even be filled into waterproof casings and steamed or cooked in a water bath at 80 °C until a core temperature of 70 °C is reached.

### 13.12 Low-fat frankfurters

A low-fat sausage contains around 30–35% water, 6–10% fat and around 50–55% lean meat. The high meat content means that this kind of sausage is occasionally rubbery, because high levels of protein result in a gummy texture. Additives such as phosphates, salt (around 1.6–1.8%), nitrite, colour enhancer, spices and starch account for around 5% of the total mass. Low-fat sausages often contain carrageenan, modified starches, konjac flour or gelatin (1–2%) to create an acceptable mouth feel and to improve succulence. Many of the lipophilic areas of the proteins in these sausages are not brought into use owing to the low fat levels, and the water-holding patterns of the activated proteins change as a result. For this reason, collagen-rich materials such as shank meat are used as the gelatin formed during heat treatment immobilizes added water. Low-fat products are produced using either the lean-meat method or the all-in method.

### 13.13 Bavarian meat loaf (Austria and Germany)

Meat loaf is eaten almost daily, and there are two main versions. One is a fine-emulsion product while the other consists of minced meat and fat materials. The fine-emulsion product is more popular, and the emulsion contains around

40–45% meat, 30% ice and water, around 25–28% fat and 3–5% powdered additives. The meat used is commonly a mixture of beef and pork, with the majority being 85–90% CL beef, and all types of pork fat are used. Around 18–20 g of salt per kilogram of product are added, and other additives include nitrite, colour enhancer, phosphates, spices and around 2–4% starch. Skin emulsion is also frequently added, usually at between 2% and 5%. The meat materials used for meat loaf are usually of slightly lower quality than the materials used for frankfurters, and meat loaf often contains high-collagen materials. The emulsion is made predominantly using the lean-meat method and then filled into open moulds. The moulds are either greased with a thin layer of fat or oil or lined prior being filled to make it easy to remove the product after cooking. The filled mould is baked in hot air at 150 °C for 30–45 min, and then the temperature is reduced to around 100 °C until a core temperature of 70 °C is reached. The finished product is removed from the mould while still warm by turning the mould upside down, and any water present is discharged at the same time. The meat loaf is then placed on racks and put in a blast chiller or chiller. Some meat loaf is fried in hot oil at 150–180 °C for 1–2 min while it is still warm, which gives it a dark-brown crust before it is transferred to the chiller. The chilled product is either vacuum packed as a whole piece or cut into slices 6–10 mm thick. Meat loaf is consumed either cold or reheated in a sandwich, and also as a main dish together with mashed potato and sauerkraut (raw fermented cabbage). Grilling, or frying, is another popular method of reheating.

### **13.14 Meatballs (Asia)**

Meatballs are eaten in soup, in sauce and as part of many rice and noodle dishes, particularly in Asia. The quality, size and flavour of meatballs vary greatly according to local eating habits.

Meatballs can be made from beef, pork or chicken. High-quality meatballs use 85% CL grade meat, and contain around 70–75% meat, 10–15% water and ice and around 10% powdered additives such as phosphates, salt (around 14–18 g per kilogram of product) and spices, together with 6–10% starch, mostly in the form of tapioca or a mixture of tapioca and corn starch. The combination of a fairly high meat content, a moderate amount of added water and high levels of starch results in a spongy-firm product, which is most often desired.

Lower-quality meatballs contain less meat, more water and fat, and often additives such as soy protein to increase the firmness and sponginess. The fine emulsion is usually made using the all-in method, and balls of different sizes are formed from the fine emulsion and dropped into containers of hot water at 80–90 °C. The meatballs are cooked in the hot water and then either they are sold directly to consumers on the same day at wet markets (daily

markets) without being packed, or they are cooled, vacuum packed and sold under refrigeration in shops. Large amounts of meatballs are also sold vacuum packed and frozen. Meatballs that are not packed are occasionally dipped into a solution containing benzoate or sorbate, which coats the surface and acts as a preservative.

# 14

## Fresh sausages

Fresh sausages, as the name suggests, are meat products sold fresh without prior heat treatment. The entire heat treatment of the product occurs at the very last point in the supply chain: the consumer's home. Generally, those sausages are grilled in the oven or barbecued. Fresh sausages are mostly stored and sold in chilled form although some are sold frozen. The frozen product is bought in the shop or supermarket. In households without a refrigerator, it is then defrosted at room temperature, which is quite commonly between 25 and 40 °C in many tropical countries, and then heat treated. Defrosting also takes place in a refrigerator or microwave.

Many countries in the world have their own specialty fresh sausage such as bratwurst in Germany, boerewors in South Africa, and barbecue sausage in Australia and New Zealand, to name just a few.

A wide variety of fresh sausages are available containing many different types and cuts of meat as well as countless different flavours. The most common materials utilized are beef, pork, mutton and poultry such as chicken and turkey. Other more exotic meats such as crocodile and fish are also used. Fresh sausages are commonly available in two basic types: either as fine emulsion-type products or as coarsely minced and mixed products.

The fat and lean-meat content of most fresh sausages is regulated in most countries in the world. As with cooked sausages, some food standards require a measure of minimum protein content. This protein content is frequently made up of a combination of protein coming from the lean meat present within the product together with added protein, such as wheat gluten or soy protein. Fresh sausages are produced according to varying quality standards and, in large parts of the world, they are sold very cheaply. Within such low-cost products, only a small percentage of the total protein present originates

from meat with the rest coming from cheaper sources of added protein. The ratio of meat protein to added protein is often determined by the selling price of the product. In countries such as Australia and New Zealand, a certain level, or percentage, of lean-meat within the sausage is required by law irrespective of the level of protein present. In conjunction with the level of meat present within the product, a maximum level of fat is permitted, based on the lean meat content. As an example, fresh sausage in Australia has to contain a minimum of 50% lean meat and a maximum of 50% fat, based on the lean-meat content. If a sausage contains 50% lean meat, the maximum level of fat within the product can be 25% (50% of the lean-meat content). If a sausage contains 55% lean meat, the maximum level of fat could be as high as 27.5%.

## **14.1 Selection of raw materials**

Because the final product has not been heat treated before purchase by the consumer, care has to be taken that microbiological contamination is kept as low as possible in order to obtain the desired shelf life and to guarantee the safety of the product.

### **14.1.1 Meat and fat trimmings**

It is absolutely critical that the meat and fat materials processed have low microbiological counts. A count of  $10^2$ – $10^4$  per gram of meat should be achieved; a maximum count of  $10^3$  per gram of meat is often seen as the standard in most processing companies. This kind of count is one important step to achieve the desired shelf life of the final product, which depends also on so many other factors such as the addition of preservatives, the level of hygiene applied during manufacturing of the product as well as the storage temperature of the finished product.

As most of the meat and fat materials processed are handled, stored and processed in either a frozen or a semifrozen state, selection on the basis of pH value and its WHC is not possible. The application of phosphates during processing will compensate for any PSE meat. The likelihood that significant amounts of DFD beef are present in any one batch is very small since a mix of beef, lamb and even pork is generally processed. Even in an all-beef product, trimmings from several animals are present and the likelihood that the majority of meat is of DFD character is very small. If a fresh sausage is made from poultry meat, thigh meat is frequently mixed with a very small amount of breast meat owing to cost constraints. Frozen chicken skin is occasionally used, provided that the bacterial count is low. Hard MDM (see Chapter 4, Section 4.2) is not permitted in the manufacture of fresh sausage in many countries. The main reason is the often elevated bacterial count of hard MDM as well as its susceptibility to fat rancidity. It also has a limited

shelf life due to the large surface area of the material (which increases the likelihood of further contamination by bacteria). The fat content of hard MDM, and especially hard MDM produced from chicken carcasses, can also vary greatly, resulting in quality differences between finished products.

Meat trimmings of 50–95% CL-grade meat from beef, pork and mutton are most often utilized for the production of fresh sausages. The combination of different CL-grade materials is based on the desired meat and fat content in the final product. Pork trimmings create a smooth texture in the product whilst beef and mutton trimmings, depending on the CL grade, contribute to a stronger colour and firm texture. Skin emulsions (see Chapter 12, Section 12.2) obtained from chicken or pork skin are seldom utilized in fresh sausages owing to their often elevated bacterial count and the reduced resulting shelf life of the final product.

#### **14.1.2 Fat and water**

Fatty trimmings of various CL grades are the preferred choice for fresh sausages over pure fat. If fat is used, it should have a low bacterial count, usually no more than  $10^3$  per gram of product. Fat utilized for the production of fresh sausages is generally solid fat material such as beef, pork or mutton fat. Liquid fat material, such as oil, is not utilized. Fat to be processed should not exhibit any signs of rancidity since rancid flavour is greatly enhanced with prolonged storage and grilling. Small amounts of fat emulsion (see Chapter 12, Section 12.3) are occasionally used. However, fat emulsions frequently have a high bacterial count, compromising safety and shelf life.

Water or ice utilized within the manufacturing process must be of drinking quality. Added water is required for solubilizing proteins, adding succulence to the product, maintenance of a low processing temperature and also for cost reasons, because water is still the least expensive material within the product.

### **14.2 Selection of additives**

Salt (see Chapter 5, Section 5.2) fulfils the same function in the fresh sausage as in most other meat products. It helps to solubilize muscular protein, which in turn immobilizes added water and emulsifies fat. Salt also adds flavour to the sausage. The amount of salt used in fresh sausage is between 14 and 16 g per kilogram of total mass, which is slightly less than in cooked sausages. This is partly because a fair amount of water and some fat are lost during grilling, increasing the salt concentration as a result. Around 4–5 g of a cutting-phosphate blend (see Chapter 5, Section 5.1.2) are used per kilogram of sausage. A blend of phosphates, instead of a single type of phosphate, is used in order to solubilize the maximum amount of protein possible within the short processing time.

As flavour and flavour intensity are very subjective, an endless variety of spices and spice blends can be introduced in order to create the flavour profile and intensity wanted. Even exotic flavours such as red wine and Indian curry are regularly used in fresh sausages. Common flavour combinations are herb and garlic, tomato and onion, tomato and bacon, herb and mustard, sweet chilli, and honey and soy. Care has to be taken in using untreated spices since they can have high numbers of bacteria present, which can reduce the safety and the shelf life of the product. Treated (decontaminated) spices or spice oleoresins are generally used to avoid bacterial contamination. Paprika oleoresin is frequently utilized for colouring purposes to give a subtle red–orange colour to the sausage. Adding paprika oleoresin also allows the manufacturer to include ‘spice extract’ on the label rather than ‘colouring’ which is more acceptable to many consumers.

Food standards in some countries do not permit the addition of preservatives to fresh sausages and the shelf life of such products is therefore very limited. In some countries, the maximum shelf life of a fresh sausage produced without preservatives is the manufacturing day of the product itself plus one additional day, provided that the product is always stored at temperatures below 4 °C. By imposing such strict rules, the safety and freshness of the product are maintained. Other countries do permit the use of preservatives such as SMBS (see Chapter 6, Section 6.4.1). SMBS is added to the sausage mass at around 1–1.3 g per kilogram of total mass or at other levels depending on the legal maximum level in the respective country. Most food standards in place in countries where SMBS is permitted refer to sulphur dioxide (SO<sub>2</sub>) rather than SMBS and the permitted maximum level is expressed in milligrams or parts per million of SO<sub>2</sub> per kilogram of sausage. As a general rule, about 50–60% of added SMBS turns into SO<sub>2</sub>, which in conjunction with other substances such as sulphurous acid, acts as the actual preservative. For example, the addition of 1 g of SMBS per kilogram of sausage mass results commonly in around 450–500 ppm of SO<sub>2</sub> in the freshly produced product. SMBS also preserves the original red meat colour in fresh sausage as it is a strong reducing agent and the sausage maintains its ‘bloom’. Being a reducing agent, SMBS donates electrons which in turn reduce the grey or brown metmyoglobin into reduced myoglobin, which is red in colour. Commonly, fresh sausages containing SO<sub>2</sub> at around 400–500 ppm shortly after being produced have a shelf life of between 10 and 12 days stored at temperatures between 0 and 4 °C.

In countries where the addition of protein to fresh sausage is permitted in order to fulfil the protein requirement within the product, proteins such as wheat gluten or soy protein (see Chapter 6, Sections 6.1.3 and 6.1.4) are frequently introduced into the product. The level of added protein depends on the amount of lean meat present. The combination of meat protein, in conjunction with added protein, must conform to the relevant minimum legal limit. This calculation must take account of the protein level in the added protein. As an example, if the level of protein within the total sausage

mass has to be increased by 2% in order to fulfil the legal requirement and a protein containing 80% of protein in the form of wheat gluten is utilized, then 2.4% gluten has to be introduced into the sausage mass to lift the protein content by 2% overall. The type of protein utilized to increase the level of protein within the product depends predominantly on availability and price because most fresh sausages are sold cheaply.

In most countries, the total protein content is determined by analysing the total nitrogen content of the sausage, since nitrogen is found in all amino acids and therefore in all proteins. The total nitrogen obtained is multiplied by 6.25, which results in the protein percentage within the product. The factor 6.25 is utilized in order to determine the level of protein based on the amount of nitrogen found because nitrogen is present within proteins at a fairly consistent level of 16% ( $100/16 = 6.25$ ). The protein value is then taken and multiplied by 4.8, which results in the lean-meat content of the sausage expressed as a percentage. The factor of 4.8 is used because the protein content of lean meat is around 21%. If lean meat is taken as 100% and divided by 21, the factor 4.8 is obtained. As a practical example, a nitrogen content of 1.85% can be multiplied by 6.25, resulting in 11.5% protein. The value of 11.5% protein is then multiplied by 4.8 which results in 55.2% lean meat. In making this calculation, it is important to take account of any added protein.

Binders or fillers are regularly used in the manufacture of fresh sausages, including materials such as starch, flour, breadcrumbs, cereal binder, powdered TVP and rusks. Commonly, quite large amounts of binders are introduced in order to absorb and hold water as well as to add texture to the product. Here as well, availability and price are commonly the deciding factors on the type of material to be introduced as most of those materials are very price sensitive. In medium-quality fresh sausages, the amount of binders introduced should be no more than 4–6%, whilst high-quality products should not contain any binder. Low-cost fresh sausages contain up to 15% binders. Hot-swelling gums, such as carrageenan, are not used in fresh sausages because the lack of heat treatment means that they never form a gel. Cold-swelling gums such as guar gum or xanthan are occasionally applied in small amounts as those materials thicken on their own and immobilize added water.

Depending on the respective food standards in place, some countries permit the application of lactate, or a lactate–diacetate blend, into fresh sausages to extend shelf life. The level of lactate is usually around 3% or 30 g per kilogram of sausage whilst a blend of lactate and diacetate is applied at around 2.5%, or 25 g, per kilogram of sausage. Nitrite is not commonly used in fresh sausages as the natural red colour of meat is usually maintained and the typical curing colour caused by nitrite is not wanted. This fact necessitates stringent control of spices or water utilized during the manufacture of fresh sausages as those materials can contain traces of nitrite, and more often nitrate, which can be reduced to nitrite within the product, causing the formation of the unwanted red curing colour. Very low levels of 2–4 ppm of

nitrite per kilogram of sausage are sufficient to cause unwanted colouring. To avoid any risk of accidental contamination, large processors of fresh sausages have production facilities for fresh sausages and other non-nitrite products totally separate from areas where nitrite-containing products are produced. If such total separation is not possible, non-nitrite products such as fresh sausages are produced as the very first product so that all machines are still clean from the clean-up the day before and no nitrite is present.

Sugars, as well as flavour enhancers such as MSG, are commonly part of the product for their contribution to flavour. Colours are only occasionally used as the original meat colour is usually not affected during production. Colourings such as fermented rice or caramel are used, depending on the colour wanted in the finished product. Care has to be taken that Ponceau 4R (E 124) is not utilized as a colouring agent as a reaction with SMBS, or more specifically with SO<sub>2</sub>, takes place, resulting in green and yellow colours inside the sausage. Red 2G is a colour frequently applied in fresh sausages as this colour is stable against the impact of SO<sub>2</sub>.

### 14.3 Manufacturing technology

The manufacturing technology of fresh sausages is quite simple but certain steps have to be followed closely in order to obtain the product wanted. During processing, the largest possible amount of protein within the lean meat present has to be activated by destroying the sarcolemma to release myosin and actin which are subsequently solubilized by the impact of salt and phosphates. Myofibrillar proteins are fibrous in nature and are turned into liquid or viscous exudate during the activation of protein, which is then chiefly responsible for the emulsification of fat as well as immobilization of added water.

Salt-soluble proteins such as actin and myosin demonstrate better fat emulsification and WBC than water-soluble proteins do. Turning fibrous protein into a liquid exudate occurs quite easily in chicken and pork but is more difficult to obtain in mutton and beef. The level of hardness in meat, based on the different thickness of the fibres present within different types and cuts, explains the different levels of solubility between different cuts within the same species. Hence, the age of the animal also has a significant impact on the solubility of muscular protein as increased age results in a higher degree of cross-links between proteins and solubility is reduced. Collagen present in muscle tissue from older animals also exhibits elevated levels of intramuscular and intermuscular cross-linking within collagen molecules. In chicken, muscular protein within white muscles such as breast is much easier to activate than fibrillar protein in thigh meat. Activated protein, in combination with added protein, binders and fillers, can result in an acceptable product, even when levels in muscle tissue are low.

### 14.3.1 Sausages made in a bowl cutter

A bowl cutter is commonly used for the production of a fine emulsified product which does not exhibit any coarse visible particles of show-meat. The all-in method (see Chapter 12, Section 12.5.2) usually involves placing frozen or semifrozen meat and fat material, which has been flaked, chipped or minced with a large blade, in the cutter. Before this, frozen blocks of meat and fat material are passed through a metal detector routinely to ensure the absence of any metal foreign bodies in the finished product. Whilst cutting under slow to medium fast speed, all the additives required, mostly in the form of a complete premix or compound, are added to the meat and fat materials.

Around 70% of the total amount of ice and water required is then introduced. The ingredients are cut under a high speed at a temperature of around 2–4 °C. At this point, the remaining 30% of ice (ice only) is added in order to cool the mass to a temperature between –3 and 2 °C. Cutting under a high speed produces a fine emulsion and incorporates the added ice into the sausage mass. The final temperature of the sausage mass is commonly kept between –2 and 2 °C to avoid any risk of bacterial growth. As an industry-standard, a maximum temperature of 0 °C is often in place for the finished emulsion. Added salt reduces the freezing point of water inside the sausage emulsion to around –3 °C, thus allowing subzero temperatures without obtaining ice from added or intramuscular water in products. Given that the final temperature of the emulsion is above –3 °C, all water within the sausage mass is present as water and not as ice. The solubility of actin and myosin is also excellent at a temperature of around 0 °C as well. The amount of ice or water utilized during the process depends on the temperature of the meat and fat materials processed. The use of deep-frozen materials makes it possible to use increased levels of water. On the other hand, a mix of slightly frozen or chilled materials requires the addition of more ice rather than water. In general, processors prefer to use water rather than ice since ice is more expensive to produce and store.

The meat and fat materials to be processed are routinely analysed to measure the level of fat and protein. It is important that these levels are correct to standardize the final products with regard to parameters such as texture, taste and colour. Excess levels of protein within a sausage, which have not been introduced to enhance firmness and texture, represent an unnecessary cost. Insufficient protein (and, in consequence, the likelihood of too much fat) increases fat and water losses once such a fresh sausage is heat treated, and reduces firmness. Effective control of the level of protein, fat and water results in a consistent and cost-effective product.

### 14.3.2 Sausage made with a mixer–emulsifier system

Producing fine emulsified fresh sausage on a large scale is regularly achieved by utilizing a mixer–emulsifier system and large paddle mixers, or other

types of mixing machine such as ribbon blenders working in conjunction with an emulsifier. Within such a system, as explained in Chapter 12, Section 12.6, several automatic filling machines can be fed by the use of one emulsifier. Once again, the all-in method involves placing all minced or chipped frozen and/or semifrozen meat and fat material into a large mixer. During mixing, additives are added as well as all the water and ice. Mixing takes place for around 10 min until a tacky mass is obtained. The temperature of the mixed mass is generally between  $-3$  and  $-1$  °C before the mass is subsequently passed through an emulsifier. A final temperature between  $-2$  and  $4$  °C is required, and temperatures between  $-2$  and  $0$  °C are generally set as standard. Several mixing machines often feed one emulsifier to create a continuous process. The emulsified sausage mass is either placed into trolleys or pumped directly to the respective filling station.

Coarse fresh sausage is commonly produced in two different ways. In one method all frozen or semifrozen meat and fat material (chipped or flaked) is minced, usually by a blade with a diameter of 4–8 mm. Mincing must produce cleanly cut meat and fat materials without smearing so that cleanly cut particles of fat and meat can be seen in the finished product. Mincer blades and knives have to be kept sharp and the speed of mincing has to be moderate. Fatty material such as that of 50–60% CL grade is occasionally minced separately with a smaller blade (2–3 mm) whilst the lean material is minced with a larger blade, usually of 6–8 mm diameter. This method has the advantage that the fat particles within the sausage are less prominent than the larger minced lean-meat particles. Such treatment results in a more favourable appearance.

The minced materials are subsequently placed in a mixer, usually a paddle mixer, and all the additives as well as iced water then added. No ice is introduced as it takes a considerable amount of time to melt cubes or flakes of ice during mixing. The use of frozen and semifrozen meat and fat materials in conjunction with ice-cold water keeps the temperature within the required range. Care has to be taken that all additives are evenly introduced and that mixing ensures even distribution. Mixing lasts until the mixture becomes tacky. The temperature of the finished mixed mass should be between  $-3$  and  $2$  °C, with  $0$  °C commonly taken as a maximum limit. The mixing elements within sophisticated mixing machines can turn back and forth, thus optimizing the mixing effect because a cold mass tends to form lumps if mixed in one direction only.

Another method of producing coarse fresh sausage is to mix the flaked or chipped, frozen and/or semifrozen meat and fat material with all additives as well as iced water until a tacky mass is obtained. Using this method, all meat and fat materials are commonly minced with a 13–20 mm blade before being placed in the mixer. The mass, including all the water and additives, is then mixed until it becomes tacky. The mixture mass should have a temperature between  $-3$  and  $-1$  °C before mincing, and between  $-2$  and  $2$  °C after the mincing process. Commonly, a temperature below and up to  $0$  °C is set as the

maximum of the minced sausage mass. During mincing, smearing of the meat and fat materials has to be avoided as a clean cut is wanted. The speed of mincing needs to be moderate and all blades and knives kept clean and sharp. Low temperatures in the non-minced and mixed mass support a clean cut as well as being a hurdle against microbiological growth. Mixing of the mass before mincing has to ensure an even distribution of all additives within the mass itself because the minced sausage mass is not mixed further.

The most important single factor during the process is the temperature of the finished product. In the case of finely emulsified fresh sausages, the emulsified product must come out from the cutter or emulsifier at a temperature of between  $-2$  and  $2$  °C. Most commonly, subzero temperatures are required for a fine emulsified product. During filling and packing of the product, the sausage mass experiences a slight increase in temperature and  $4$  °C is, from a microbiological standpoint, the critical point after which unwanted bacteria start to grow. As fresh sausages are sold in an uncooked state, this low temperature is a critical hurdle in controlling bacterial growth. This also explains why temperatures below and up to  $0$  °C are preferred in the sausage mass before filling, keeping the temperature below  $4$  °C once the product is filled. For that specific reason, all the various processing steps such as cutting of the frozen or semifrozen material, mixing and mincing usually take place under chilled conditions between  $2$  and  $6$  °C to avoid any unnecessary rise in temperature within the sausage mass.

### **14.3.3 Filling**

Fresh sausages are usually filled into small-diameter collagen casings and the diameter chosen varies commonly from 18 to around 32 mm. Most of those products are filled into 20–24 mm casings. Sheep or pig casings are occasionally used for higher-quality fresh sausage. If natural casings are used, the casing must have a low bacterial count. Filling of a fresh sausage takes place commonly using vacuum fillers. Filling of fine-emulsion products takes place at a high speed and filling of sausages containing show-meat (coarse products) at a moderate speed so as not to minimize the appearance of particles in the finished product. The application of vacuum during filling is important because high levels of oxygen present in fresh sausage could lead to unwanted discolouration. If collagen casings are used, surfaces of the casing must be kept clean and dry during filling. Contact with surface water compromises safety and shelf life and promotes discolouration. During filling, the temperature of the sausage mass should not exceed  $4$  °C, and a maximum temperature between  $-2$  and  $0$  °C is commonly aimed for.

### **14.3.4 Packaging**

Fresh sausages are often packed in foam trays and wrapped with plastic film. The wrapping process is usually fully automatic or semi-automatic. Care has

to be taken that contamination during packaging is avoided as any newly introduced bacteria may compromise safety or shorten the shelf life of the sausage. Staff hygiene has to be of the highest standard, including the use of sterile protective clothing such as gloves, beard or hair nets, caps and mouth masks. All packaging as well as wrapping equipment must be kept clean and free of bacteria. The formation of condensation water (see Chapter 4, Section 4.12) has to be avoided during filling and packing as free water on the surface of the products provides an excellent reservoir for bacteria. The temperature in the packing area has to be low to ensure that the sausage mass maintains a temperature of around 0–4 °C. Filled sausages maintained at a low temperature have often been transferred to a packaging room with significantly higher temperatures, exceeding the temperature at which condensation forms. As a result, condensation water collects, threatening to shorten shelf life and to affect the colour stability of the product. During packing, the internal temperature of the sausage should not be above 4 °C in order to avoid microbiological growth. This is particularly important as fresh-packed sausages are commonly placed into cartons, or boxes, which are then placed on pallets. Even if the pallet is stored at 0 °C, sausages at a higher temperature stored in a box in the middle of a pallet would take some time to reach a temperature below 4 °C, thus reducing shelf life.

Pressure marks on fresh sausages which are tray packed and wrapped with foil are commonly a sign of oxygen (O<sub>2</sub>) deficiency where sausages with low levels of preservatives are in close contact with each other. Within those pressure marks, myoglobin is ultimately turned into metmyoglobin as diffusion of O<sub>2</sub> occurs. Greying takes place as low levels of preservatives fail to stabilize the original colour and the processes of reduction and oxidation on myoglobin finally change the colour of the product. Whitish spots on fresh sausages can be seen sometimes where sausages are in close contact with each other. Localized oxidation also plays a major role in conjunction with low levels of preservatives. Over time, those white spots form greyish to black rings, which grow larger during extended storage. Processed fat with a high number of peroxides as well as low levels of SO<sub>2</sub> contribute to the formation of those grey spots. Using binders with a high bacterial count increases this type of discolouration. In fresh sausages where paprika oleoresin is used for colouring purposes, fading in colour is a common problem over a prolonged period of time. This is especially true if the shelf life of the product is 12 days or more and the product is exposed to light since oleoresin reacts with light. There are several different levels of quality of paprika oleoresin on the market which differ significantly in their degree of colour stability. The addition of tocopherol or rosemary extract (0.05–0.1%), or a combination of both, to the paprika oleoresin stabilizes colour for longer. However, colour in fresh sausage using paprika oleoresin will always fade over time under the impact of light, O<sub>2</sub> and temperature, or a combination of these, since no paprika oleoresin can be fully stabilized against oxidation.

Blue spots can occasionally be seen in fresh sausage. They are chiefly

caused by pieces of skin or rind located underneath the casing. Such bluish spots can also be the result of the presence of binders such as cereal binder, starch, flour or rusk containing residual levels of iodine-based cleaning materials as iodine shows strong reactions with preservatives such as SMBS. Cold temperatures, as described above, during the manufacture, filling and storage of the product, delay the fading of colour in the sausage.

Medium- to high-quality fresh sausage is frequently modified atmosphere packed in deep trays and a combination of nitrogen ( $N_2$ ) (60–70%) and carbon dioxide ( $CO_2$ ) (30–40%) is commonly applied.  $CO_2$  is the material actually extending shelf life as carbonic acid is formed on the surface of the product which exhibits bacteriostatic properties.  $CO_2$  also interferes with metabolic activities of several pathogens and spoilage bacteria, thus increasing the shelf life further. As  $N_2$  is an inert gas and therefore does not react with anything, it fulfils the function of replacing  $O_2$ . The level of  $O_2$  within the modified atmosphere should be below 0.6%. By packing products into deep trays and applying a modified atmosphere, the product lies more loosely within the packaging and no deformation of the product occurs as is often the case if the product is wrap or tray packed. The tight alignment of the wrapping foil on to the sausage leads to some degree of deformation of the product. Modified-atmosphere-packed products placed in trays are covered automatically with the packaging foil. The covered tray passes through a heat tunnel for a short period of time, causing the foil to shrink tightly around the tray as a result. Passing through the heat tunnel does not increase the temperature of the product itself and labels are generally applied automatically to the packed product afterwards.

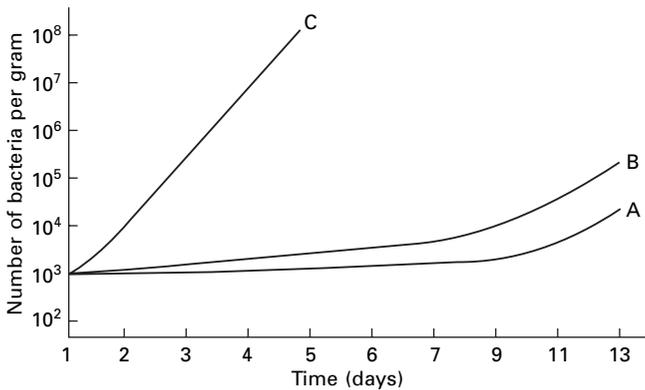
The firmness of a fresh sausage generally increases during the first 24–48 h after filling if fillers such as starch, flour, cereal binder or rusk are part of the recipe. Added water is more effectively absorbed and incorporated into such materials over this period, predominantly via the capillary effect. During this period, activated protein from meat also demonstrates a protein–protein interaction with protein from binders as well as added non-meat protein. Finally, protein–fat interaction between protein in the meat and binders also stabilizes over time. All these processes are collectively known as ‘the setting’ of a fresh sausage. Firmness in fresh sausages decreases over a prolonged period time as all interactions described above, including the capillary effect, are weakened unless stabilized through the impact of cooking the product.

#### **14.3.5 Storage**

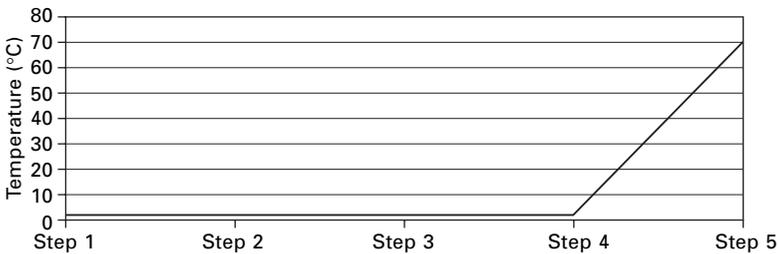
Storage of the packed product should take place between 0 and 4 °C in order to minimize microbial growth. A storage temperature of around 0 °C is commonly used. There are significant differences between the shelf life of products stored at 0 °C and that of products stored at 4 °C. However, bacterial growth is still slow at 4 °C. On the other hand, each degree above 4 °C

shortens the shelf life dramatically as growth of bacteria takes place exponentially. Figure 14.1 demonstrates the impact of shelf life of a fresh sausage containing SMBS stored at different temperatures such as 1 °C (curve A), 3 °C (curve B) and 7 °C (curve C). The figure shows clearly that only a little difference is seen between the sausages stored at 1 and 3 °C. On the other hand, a storage temperature of 7 °C rapidly shortens shelf life and bacteria counts of  $10^6$ – $10^7$  per gram of sausage are quickly obtained.

Maintaining a temperature between 0 and 4 °C in the product during transport of the product from the manufacturer to the shop as well as during storage of the sausage on a shop level frequently proves to be a problem. Figure 14.2 shows the temperatures to be observed during the processing steps of producing the product (step 1), after filling (step 2), during transport (step 3), during storage in the shop (step 4) and after heat treatment before consumption (step 5). In addition, products should be kept out of direct light to minimize discolouration, particularly where paprika oleoresin is present within the sausage for colouring purposes.



**Fig. 14.1** Spoilage of fresh sausages stored at 1 °C (curve A), 3 °C (curve B) and 7 °C (curve C).



**Fig. 14.2** Temperature changes during the processing of fresh sausage.

#### 14.4 Summary of critical production issues

- 1 All meat, fat and skin material utilized should have a low bacteria count (around  $10^2$ – $10^4$  per gram of product) with no rancid fat.
- 2 Equipment utilized for the manufacture of the product must exhibit a high standard of hygiene before use with no residue of disinfectants present.
- 3 The maximum level of preservatives such as SMBS, if permitted, should be applied as well as salt.
- 4 The maximum temperature of a finely emulsified or coarsely minced and mixed fresh sausage after filling is 4 °C and preferably temperatures of around 0 °C should be achieved at this point
- 5 Recontamination of the product as well as formation of condensation water must be avoided during packing, and the degree of staff hygiene has to be high during the entire manufacturing process.
- 6 A temperature below 4 °C needs to be maintained during transport of the product to the shop.
- 7 Storage of the product in the shop should be at a maximum temperature of 4 °C.

## 15

# Typical fresh sausage products from around the world

### 15.1 Nuremberg bratwurst (Germany)

This well-known type of bratwurst is made only from pork, commonly 75–80% CL grade and minced with a 5 mm blade. Additives used are phosphates (3–5 g per kilogram of the total mass), salt (16–18 g per kilogram of the total mass) and spices such as pepper, cardamom, mace, ginger, marjoram and lemon. The amount of iced water added is between 5% and 10% and all is mixed until a tacky mass is obtained. Nitrite and preservatives such as SMBS, as well as fillers such as starch, are not utilized.

Another method of producing Nuremberg bratwurst is first to obtain a base emulsion made from lean pork (95% CL grade) by adding around 30% ice to the meat together with phosphate and salt. The lean meat is placed in a bowl cutter, and phosphates, salt and around 70% of all ice are added during cutting of the mass under a high knife speed. Once the mix reaches 4–6 °C, the remaining ice is added, causing the temperature of the base emulsion to drop to around 0 °C. After a while, the cutting process causes the temperature of the base emulsion to rise again. The process is completed once a temperature of around 2–4 °C is obtained. Pork, of 75–80% CL grade and minced with the 5 mm blade, is then gently mixed with the base emulsion which serves as a binding glue for the minced pieces of meat and fat. During mixing, salt and spices are added to the minced fatty meat. Generally, the amount of base emulsion is between 25% and 30% of the total mass. The sausage mass is then filled into small-diameter sheep casings of around 18–24 mm diameter and 7–9 cm long, weighing around 25–35 g each. Traditional Nuremberg bratwurst is sold fresh and the shelf life is generally the day of production and the following day (2 days in total). However, Nuremberg bratwurst is also sold as a cooked product nowadays.

## 15.2 Boerewors (South Africa)

Boerewors in South Africa is a coarse loose-textured sausage containing spices such as cloves, nutmeg, coriander and garlic, as well as allspice and other seasonings influenced by regional traditions. Besides salt (16–18 g per kilogram of total mass), vinegar is also commonly added and has an impact on taste and shelf life through the presence of acetic acid. Fresh, and not frozen, meat is processed and beef, pork and mutton are often combined. The use of top-grade meat is not essential, but connective tissue is usually removed prior to processing. Meat from young animals is preferred.

Well-chilled fatty trimmings (0–2°C) are minced quite coarsely with a 13 mm blade, as the mixing of materials with a smaller blade would bind the mix too much and produce too firm a texture in the final product. The fat content of boerewors is around 25–30%. MDM is not utilized and 5–10% iced water is added and is mixed until some degree of tackiness is seen. The mixture is then minced with a 4–5 mm blade. The minced sausage mass is filled loosely into pork casings and the sausage is stored for 1–2 days under chilled conditions for the casing to dry out. Boerewors is barbecue grilled commonly in a coil form and not as a portioned product.

## 15.3 Barbecue sausage (Australia)

Barbecue sausage in Australia is primarily a finely emulsified sausage produced by following the mixer–emulsifier system. Frozen and semifrozen fatty beef and mutton trimmings of 50–85% CL grade are placed in the mixer after being chipped, flaked or minced. All additives such as phosphates, salt (around 16 g per kilogram of total mass), spices, SMBS (around 1.0–1.1 g per kilogram of total mass) and fillers such as wheat starch, flavours, cereal binder and rice flour are added and mixing commences. Nitrite is not used. The proportion of fillers used is between 30–100 g per kilogram of total mass. After a short period of mixing, all the iced water (20–24%) is introduced and the entire mass is mixed for around 7–10 min until all the added water is well absorbed and a tacky mass is obtained.

The mixed mass, made from fatty trimmings, contains at least 50% lean meat. Fat is present at around 20–22% with the remaining amount made up from water (20–24%) and additives. After passing the mixed mass through an emulsifier, the sausage mass reaches a temperature between –2 and 1 °C before being filled into 24–28 mm collagen casings. The filled product is predominantly tray packed and covered with a plastic film. The shelf life is between 10 and 12 days and the product is stored at 4 °C. Fresh sausage is mostly grilled and eaten in a bun, together with countless different types of sauce as well as condiments such as mustard, fried onions, cheese and sauerkraut.

### **15.4 Chicken sausage (Australia)**

Semifrozen chicken thigh and breast meat is minced with a 6–8 mm blade whilst semifrozen chicken skin is minced separately with a 3–4 mm blade. All minced materials are placed in a paddle mixer and all the additives (as listed in the description of the Australian barbecue sausage in Section 15.3) are added. Once all the additives are evenly introduced, iced water is added and the entire mass is mixed until all the added water is well absorbed and a tacky mass is obtained showing a temperature between  $-2^{\circ}\text{C}$  and  $+2^{\circ}\text{C}$ . Chicken sausage also has to contain at least 50% lean meat and around 10–15% chicken skin is usually stipulated in the recipe. Water is added at around 25–30% and the remainder is additives as described in Section 15.3. Coarse-minced chicken sausage is frequently filled into 28–32 mm hog casings to give an old-world look to the product. It is commonly modified atmosphere packed in deep trays, lying loosely within the packaging. The shelf life of the sausage is also between 10 and 12 days and grilling is the preferred choice of final preparation.

### **15.5 Merguez (France)**

Merguez is commonly made by two different methods similar to Nuremberg bratwurst (see Section 15.1). One method involves mincing fatty beef and pork with a 3–4 mm blade with around 10% iced water added during mixing. The minced meat and fat materials are mixed with phosphates and spices. Paprika is the main spice together with garlic, coriander and pepper. Besides spices and phosphate, salt is added at around 1.8%, and nitrite is commonly applied as well. Chillli may also be added. The mixed mass is filled into 24–28 mm collagen casings.

The second method is to obtain a base emulsion first made from 90% CL-grade lean meat with around 30% ice added to the meat in a process as described in Section 15.1, utilizing phosphates, salt and nitrite. The total sausage mass is commonly made from around 30–40% base emulsion and the other 60–70% consists of minced (3–4 mm) fatty pork and beef trimmings. During mixing of the base emulsion, all the spices as well as salt and nitrite are introduced before being filled into casings. Occasionally, merguez made this way are also sold in cooked form.

### **15.6 Cumberland sausage (Great Britain)**

Cumberland sausage is made from pork from the shoulder or belly as well as pork fat itself. A typical recipe for Cumberland sausage would contain around 30% meat of around 85–90% CL grade, 15% belly meat, 10–15% pork back fat, 15–20% rusk and around 25% iced water. All these meat and fat materials

are placed in the bowl cutter and are cut under a medium–fast speed with the addition of iced water, spices, salt (1.6–1.8%), phosphate and occasionally nitrite. The major spices utilized are black pepper, mace and quite often sage. The sausage mass is cut to a particle size of 3–4 mm and subsequently filled into hog casings with a diameter of 28–32 mm. Cumberland sausage is commonly presented in a spiral shape. Another simpler method of production is to mince all meat and fat materials with a 3–4 mm blade followed by subsequent mixing, where all the additives, spices and iced water are added, until a tacky mass is obtained.

### **15.7 English breakfast sausages (Great Britain)**

English breakfast sausages are fresh sausages typically containing around 20% lean pork shoulder meat of 90% CL grade, 10% jowls, 25% pork fat trimmings, 10–15% rusk and around 30% ice. All meat and fat materials are processed in a slightly frozen condition and additives such as salt (1.4–1.8%), phosphates (3–5 g per kilogram of total mass) and spices are added. The main spices used are pepper, mace as well as nutmeg, and SMBS is used as a preservative. Commonly, 1–2% starch is also used as well as around 2–3% soy protein. The entire mass is cut in a bowl cutter until a finely cut mass is obtained and the final temperature of the sausage mass is between –2 and 0 °C. The finished sausage mass is commonly filled into collagen casings of 24–28 mm diameter. Another method of production is for coarsely minced meat and fat materials to be mixed with additives, spices and iced water until a tacky mass is obtained before being minced with a 2–3 mm blade.

## 16

### **Raw fermented salami**

The production of raw fermented salami goes back hundreds of years as it was quickly discovered that shelf-stable meat products could be produced by adding salt to meat and subsequently drying the product. Fermentation of foods has been carried out for thousand of years. In earlier years, nothing, or very little, was known about parameters such as pH value and water activity but safe products were still made by relying on empirical know-how. Even today, with all the help of modern technology, know-how and practical experience are still highly sought after!

Salamis produced worldwide vary dramatically in quality and the methods of production vary greatly too. Sliceable fermented salami is a comminuted meat product consisting of meat and fat, sold raw, or in a non-heat-treated state, to the final consumer. Production of fermented salami is sometimes described as ‘controlled spoilage’ (i.e. souring and drying) of meat. Generally, salami is not a ‘healthy’ product because the level of fat is commonly quite high. The level of salt added is also high, resulting in a high level of sodium within the finished product. Also, contrary to most other meat products, salami is one of the very few meat products where no water is added during the manufacturing process. In fact, the opposite takes place and water is removed to optimize firmness, shelf life, sliceability and flavour.

In parts of the world such as Italy, Spain, Austria and Hungary the production of salami seems to be a very simple process but in fact production of a safe good-tasting product relies on extensive knowledge and experience gained over hundreds of years. In fact the manufacture of salami is seen commonly as an art. Having proper equipment also plays a significant role within the production of salami because vital changes within salami during fermentation and drying are controlled by outside parameters such as temperature, humidity

and air speed (or airflow). The combination of working with raw materials, producing a raw fermented product and having to take account of outside parameters make the production of salami a real art form. Fermented sausages are generally very stable products and, if certain parameters are followed during their manufacture, traditional well-loved salamis can be made in a safe way. The ultimate aim when making salami is to obtain a product with a strong and stable curing colour, excellent sliceability and slice coherency, typical salami flavour and, most of all, microbiological stability.

The manufacture of salami is highly complex as product-internal parameters such as  $A_w$ , the pH value, the RH, the buffer capacity of proteins, the presence of nitrite and nitrate and the loss in weight change during fermentation all have an effect on the colour, taste, aroma and texture of the final product. As mentioned above, external parameters such as the temperature, RH in the fermentation room, air velocity, ripening time, application of non-application of smoke and/or the addition of mould also play a role. Furthermore, other parameters that can vary in a salami are the type and level of meat utilized, the level of fat, the initial pH and  $A_w$  value of the meat and fat materials processed, the type and amount of sugar added, the level of salt, spices, the presence and type of starter cultures, the particle sizes of meat and fat, the diameter of casing chosen and whether the salami is made in the bowl cutter or with a mincer-mixer system. It is quite obvious by now that the manufacture of raw fermented salami is a highly complex process.

## 16.1 Selection of raw materials

As sliceable raw fermented salami is by definition never heat treated, it is essential that all raw materials are of the standard required to manufacture a safe product. This refers primarily to the microbiological status of meat and fat material to be utilized because large numbers of bacteria can interfere badly with fermentation and unsafe products could easily be produced. In general, to produce a safe finished product, good-quality raw materials with a low bacteria count must be used.

### 16.1.1 Meat

Basically any type of lean meat can be used for the production of salami and some exotic meats such as venison, buffalo and kangaroo are already used. Pork is in most places in the world the preferred type of meat except in countries where pork cannot be eaten because of religious or cost constraints. A major difficulty during salami manufacture is that the degree of acidification of the lean meat during fermentation is hard to foresee. This is because neither the initial pH value nor the level of sugar in the meat are ever exactly the same and therefore, the buffer capacity of amino acids present in meat (even meat of the same type) is not always the same. Owing to its naturally

higher glycogen level, meat from horse and deer (venison) acidifies significantly more than the lean muscle tissue of beef and pork. The level of glycogen is higher in horse and deer meat because these animals run around as they are raised, which is not really the case any longer for cows and pigs. When processing beef and pork, the pH value within salami is reduced by around 0.15–0.3 pH units as a result of the natural sugar (glycogen) content. Horse meat acidifies salami in a much more significant way, however, and the drop in pH value can be as large as 0.7–0.8 pH units when all the lean meat used comes from a horse. Deer meat commonly has highly varying levels of sugar depending on the method of killing. Venison killed in an abattoir exhibits generally higher levels of sugar within muscle tissue than venison shot by hunters, as animals shot in the wild are not always instantly killed and during the attempt to flee high amounts of glycogen are used up.

Salami is produced either from lean muscle tissue and fat or a combination of lean muscle tissue, fat and fatty meat trimmings. There is no significant disadvantage in using fatty trimmings as long as the desired level of fat in the finished product is obtained. Quite commonly a combination of lean meat, fatty trimmings and fat, such as pork fat, is used.

In the production of salami, small amounts of chilled meat are utilized to regulate the temperature of the sausage mass overall. The chilled meat should be stored at temperatures below 4 °C as temperatures below this level do not permit bacteria such as *Staphylococcus aureus* or *Salmonella* spp., two of the most significant pathogens in raw fermented salami, to grow. Carcasses should be chilled after slaughter quickly to avoid bacterial growth overall.

The level of hygiene during the slaughtering process itself is critical in determining the bacteria count of the meat. If intestines are opened and the gut contents come into contact with meat on the carcass, those affected areas should not be washed down with water as the bacteria would be distributed over the carcass to a greater extent. Contaminated areas should be cut free by removing the area with a knife and then no further contamination of the carcass can take place.

By far the largest amount of meat utilized for the manufacture of salami is processed in either a frozen or semifrozen state and, during partial thawing, bacterial growth has to be kept to an absolute minimum. The surface of tempered meat is particularly prone to rapid bacterial growth during further thawing. Partially thawed, or tempered, meat displays a temperature of between –10 and –5 °C. Frozen and/or semifrozen meat acts as a cooling agent for the fat present within the sausage mass during cutting in the bowl cutter or during mincing and a frozen fat surface during comminution is maintained. As a result, fat is cleanly cut in the bowl cutter or during mincing, and less smearing occurs which is very beneficial during the drying phase of salami. Freezer-burned meat (see Chapter 4, Section 4.8) frequently displays discolouration on the surface and should be avoided. Even the leanest meat contains some fat, and meat stored between –18 and –20 °C should not have been placed in the freezer for longer than 8–12 months. Some degree of

rancidity develops over time which has a negative impact on the flavour in the finished product.

Meat utilized for the production of salami must not contain glands, sinews or blood clots. Glands commonly exhibit a high number of bacteria which can interfere with fermentation and blood clots are also very susceptible to spoilage as they commonly have a high bacterial count as well. Sinews should be removed because fermented salami is never exposed to heat treatment and sinews present within the product always remain tough.

The bacteria count of meat to be processed should be as low as possible and a value between  $10^2$  and  $10^3$  g per gram of meat is seen as optimal. A value above  $10^5$  per gram of meat should be seen as the maximum and the number of Enterobacteriaceae overall should be less than  $10^4$  per gram of meat. Any unwanted bacteria introduced into the raw salami mass compete with starter cultures (if utilized) for food during fermentation and can cause the fermentation to go out of control.

The pH value of meat to be processed should be below 5.7–5.8; WHC is not a desired quality as the salami should decrease in weight during production. It is disadvantageous to use DFD meat (see Chapter 4, Section 4.1) as DFD meat has undergone incomplete rigor mortis and is microbiologically not as stable as fully acidified meat, which underwent complete rigor mortis. The high pH value in DFD meat also correlates with a high WHC. A high WHC is not desired in the production of salami as the aim is to remove water from the product. An increased pH value also often correlates with a slightly increased bacteria count because elevated pH values favour bacterial growth as well as enzyme activity. Using DFD meat can also cause difficulties during the acidification of the salami and the pH value could, as a result, not decline to the desired level, therefore putting the safety of the product in question.

High pH values in meat are also not beneficial for the development of the curing colour in the finished product as less undissociated nitrous acid is present and a reduced amount of nitric oxide (NO) is obtained (see Chapter 7, Section 7.3). Beef meat from cows rather than bulls is often preferred as it demonstrates a darker colour which is an advantage when producing salami. Cow meat is preferred for several reasons. As well as having a higher level of myoglobin than the meat of young bulls which is beneficial for a strong curing colour, cow meat generally exhibits a slightly higher level of glycogen than meat from bulls, therefore acidifying in a more significant way. It is less expensive than other beef meat and also exhibits a lower water activity than muscle tissue from younger cattle, which shortens the drying process.

PSE meat (see Chapter 4, Section 4.1) has no disadvantage within the production of salami as a reduced WHC aids the loss in weight during drying. However, if the level of PSE meat within a batch of salami containing high levels of pork is higher than 20–25%, a loss in colour can be observed. Small batches of salami made with pork meat from only one pig can be problematic if the pig has PSE-character meat. In larger batches a mix of meat originating from several different pigs is commonly processed and the

risk of pale colour in the finished product due to high levels of PSE meat is minimized.

Meat materials utilized for the production of salami must be free of any residual antibiotics as those substances interfere badly with fermentation and faulty products will be obtained. Pork neck and pork shoulder are prone to contain pus and therefore, if meat from the neck and shoulder is used, several cuts should be made by knife into the meat prior to freezing to check that there is no pus within muscle tissue. This is especially the case if those cuts are from sows, as injections, a cause of pus formation, are commonly performed by veterinaries in the neck of sows.

When pork is used, sow meat (old female) is a preferred choice of material as it has a strong red colour, is commonly less expensive than normal pork and also exhibits a slightly reduced  $A_w$  compared with pork meat from young pigs. A decreased  $A_w$  shortens the period of drying, which can be an economic benefit. Generally, meat from all different cuts from sow, such as shoulder, belly, leg and loin, can be utilized for sliceable salami. From the belly, the soft areas along the nipples as well as the flank part in front of the leg should be avoided for the manufacture of salami because those areas contain fat with a high level of unsaturated fatty acids. That fat is very soft in consistency and the fat is easily smeared during cutting or mixing, which has a negative impact on drying afterwards. Fat of such soft consistency can be perfectly utilized for spreadable raw sausage, cooked sausage such as frankfurters, and liver sausages.

Cuts of fresh chilled meat from the carcass of sows such as shoulder, neck and belly are frequently preconditioned prior to use or being frozen and are hung in a chiller at a temperature approximately between  $-2$  and  $0$  °C under high air velocity for 2–3 days in order to remove a fair amount of moisture even before the material is introduced in the salami mass. This semifrozen material is often used to raise the temperature of the salami mass to around  $0$  °C when all other meat and fat materials used are fully frozen. If all the meat materials were fully frozen, the temperature of the sausage mass would be too low for proper fermentation afterwards. Around 10% of minced chilled (2–3 mm) meat is added at the end of the cutting process to the cut salami mass to raise the temperature of the sausage mass. During mincing, a temperature below  $4$  °C must be maintained to avoid growth of bacteria.

Another way of utilizing the predried and semifrozen material described above is in salami in which all meat and fat materials are minced in order to obtain the desired particle size. Frozen meat and fat materials are all minced at the same time and the addition of the semifrozen materials raises the temperature of the total sausage mass to the desired level. The same principle applies to salami made in the bowl cutter and the introduction of around 15–25% semi frozen materials into all the other fully frozen materials raises the temperature of the total mass to around  $0$  °C overall.

Freeze-dried meat can be used to lower the  $A_w$  right from the beginning of the fermentation process. The maximum amount of freeze-dried meat added

to a batch of salami is around 10% of the total amount of meat as the addition of excess levels would reduce the  $A_w$  below 0.95 at the beginning of fermentation and starter cultures such as *Lactobacillus* spp. would have insufficient free water to ferment added sugars into lactic acid. If this were the case, acidification within the product would not occur properly and very poor curing colour, no slice coherency and a microbiologically unstable product would be obtained (see Section 16.3.3).

Soft MDM meat (see Chapter 4, Section 4.2) is also used in the production of salami and is predominately introduced into minced coarse salami products. Materials that are high in connective tissue such as shank meat or other trimmings are put through a soft MDM machine and such material, which generally exhibits a particle size of 4–6 mm, can be used perfectly well for salami. Material to be put through the separation machine is placed in an area with a temperature between approximately  $-2$  and  $0$  °C overnight and is minced afterwards with a 13–20 mm blade before being processed in the soft MDM machine. The low temperatures of the meat material encourages a clean mincing process of collagen-rich materials and the MDM machine can separate collagen from lean meat more effectively afterwards as well.

The non-meat part originating from the separation process is mostly connective tissue which can be perfectly utilized in cooked sausages such as frankfurters or even turned into a material used in salami. To make it useable for salami, the connective tissue is placed into waterproof casing and cooked for around 3–4 h at around 90 °C. During this thermal treatment, a large amount of connective tissue, and more precisely collagen, becomes softened and some even turns into gelatin. Following cooking, the casing is removed from the still hot product and the cooked material is placed into trays which are stored in the freezer. The frozen material can be cut with a frozen-meat cutter and subsequently turned into a dust-like substance by cutting the fully frozen material in the bowl cutter with sharp knives. The dust-like material can be introduced at levels of around 1–2% into salami without changing the product overall.

Salami produced from chicken meat mainly contains thigh meat as thigh meat results in a significantly stronger curing colour than chicken breast meat does. Thigh meat is also considerably less expensive than breast meat.

Hard MDM (see Chapter 4, Section 4.2) is not utilized in raw fermented sliceable salami as it often has a high bacteria count as well as a large surface area. Hard MDM also frequently contains up to 15% fat and, as it has such a high level of fat present in a large surface area, it is very prone to rancidity. Most countries in the world do not permit the use of hard MDM in raw fermented salami by law.

### 16.1.2 Fat

Fat is cheaper than lean meat and therefore 25–35% fat is commonly added to salami raw materials. During drying, a process in which water is

predominantly lost from lean meat, the level of fat in the fully dried salami rises to 40–50%, depending on the degree of drying loss as well as the level of fat introduced initially. Fat, or very fatty trimmings, are processed in a frozen state as smearing of fat during processes such as cutting or mincing has to be avoided.

Pork back and neck fat contains a higher level of unsaturated fatty acids than beef fat and is therefore more prone to rancidity and has a lower melting point as well. In spite of this, pork fat is the most commonly utilized type of fat for salami manufacture as it demonstrates organoleptic properties far superior to beef fat. Pork back fat and neck fat are the hardest fats within a pig and are therefore the first choice when producing salami owing to its low content of unsaturated fatty acids such as oleic and linolenic acid compared with fat from other parts of the pig. Fat from the neck and loin (back fat) has the lowest number of unsaturated fatty acids and therefore does not smear as easily during cutting or mincing as soft fat from the shoulder or leg. Soft-textured fat, such as that from the shoulder or leg, has higher levels of unsaturated fatty acids which reduce the firmness and melting point of the fat. Different levels of hardness within the same piece of fat can be seen. Fat from the loin, for example, consists of several layers of fat, with the layer directly underneath the skin being the softest and the layers closer to the inside of the carcass being of harder consistency. The level of saturated fatty acids within the different layers of fat increases from the outside inwards and subcutaneous fat has the highest number of unsaturated fatty acids. Fat within pork belly is also of much harder consistency than soft fat from shoulder or leg. Generally, the hardness of fat is also influenced by the content of connective tissue within fat, and fat tissue from older pigs is firmer overall.

Fat materials utilized for salami must not be rancid and pork fat should be white, or whitish, in colour. As with lean meat, the bacteria count should be as low as possible (around  $10^3$  per gram of fat) and no remains of pork skin must be present on the fat. The deskinning machine has to be adjusted so that, during the separation of skin from fat, no skin remains on the fat itself but as little as possible of fat remains on the skin. Beef fat as such is hardly utilized in salami. Beef fat is commonly found in fatty beef trimmings, however, and so can be found in this form in salami. Pure-beef salami is commonly produced from fatty beef brisket, especially in countries where people do not eat pork owing to religious belief.

Different levels of fat within the salami mass influence the pH value to a degree since fat has a higher pH value than muscle tissue. High levels of fat increase the pH value of the sausage mass slightly but are of no, or very little, significance during fermentation. The impact of high levels of fat on the  $A_w$  of salami, however, is much greater because fat contains only around 15% water whilst lean meat contains around 75% water. A recipe high in fat has a lower  $A_w$  than a recipe 'low' in fat at the beginning of the fermentation process. As a result, the RH has to be higher at the beginning of fermentation to avoid case hardening.

The fat utilized must not be rancid as, over the prolonged period of fermentation and subsequent drying, the level of rancidity would increase exponentially. The type of feed given to pigs has a major impact on the composition of the fatty acids finally present in fat. Feeding of oily substances results in fat demonstrating high levels of unsaturated fatty acids, thus softening the fat material. Increased levels of unsaturated fatty acids also speed up rancidity.

Loin and neck fat from sows is commonly preconditioned for 2–3 days at between  $-4$  and  $-2$  °C under a high air speed prior to freezing. This reduces the level of moisture within the material so that less water needs to be removed during drying of the salami. During this process the water content of fat is reduced by around 5% and the melting point is increased at the same time (altered fat structure).

Beef fat from cuts such as brisket with high levels of saturated fatty acids can be used within salami if it is frozen and then cut in the bowl cutter under a high speed to obtain a dust-like material. This dust-like material can be introduced into almost any type of salami at around 1% without changing any product characteristics. The use of beef fat in salami is economically beneficial as beef fat would otherwise generally be discarded and has no value. In most cases, manufacturers even have to pay for the fat material to be picked up for disposal. Obviously the beef fat utilized must show an excellent microbiological status.

#### *Fat and meat replacers in salami*

Lean meat is the most costly of all the raw materials used within salami. Quite a large amount of salami is sold at a low price (to be used, for example, as pizza topping) and meat replacement is one of the very few possibilities to lower the cost of the raw materials of salami.

A gel consisting of soy isolate and iced water in a ratio of 1:3 can be used as a meat replacer in salami production. The soy isolate used for such an application must demonstrate high gelling properties. Iced water is placed in the bowl cutter and soy is added into it whilst cutting at a medium–fast speed and, after cutting for only several minutes, a spongy-firm dry mass is obtained. Colours such as fermented rice, carmine and/or caramel are needed to simulate a meat-like colour within the gel. Those colours are introduced into the water first and fully dispersed before soy is added. The colour of the gel has to be quite dark as the colour of meat within salami darkens during drying whilst the colour of the gel remains unchanged. The colour of the gel made therefore has to be very similar to the colour of the meat within the salami after drying is completed. The spongy-firm gel is removed from the cutter, placed into trays and stored under chilled conditions overnight. A firm, spongy and sliceable gel will be seen next day, which can be introduced into the salami mass.

It is common to substitute between 5% and 30% of the total lean meat content and the gel is to be treated as lean meat during the process. During

fermentation, acidification also stabilizes the granules of gel against microbiological spoilage. Coloured and flaked TVP, soaked with water in a ratio of 1:3 for 15–30 minutes, is also used as a meat replacement.

Replacement of fat within salami is sometimes desired even though it is well known that salami is not a lean or low-fat product as such. Fat can be replaced in salami using a soy isolate–oil emulsion. The emulsion can be made from 1 part of soy isolate, 2.8 parts of iced water and 2 parts of oil. The iced water is placed in the bowl cutter and high-gelling soy isolate is added into it whilst cutting under a medium–fast speed. Once all water is fully absorbed by the soy protein and a dry mass is obtained, oil is gradually added. Introducing oil lightens the colour of the emulsion and, once the oil is fully emulsified, the mass is removed from the cutter and placed into the chiller overnight to firm up.

Another method of replacing fat in a salami is to produce a fully cooked emulsified sausage. A white-coloured sausage can be produced using chicken meat, chicken skin emulsion and starch. The recipe for this type of cooked sausage, used finally as a fat replacer in salami, contains around 60–70% fatty chicken meat, 15–20% chicken skin emulsion and around 10–15% water or ice. Additives introduced are phosphates, salt, nitrite and starch with starch being added at a level of between 4 and 6% based on the total mass. The aim is to obtain a spongy-firm white-coloured emulsion, which is filled into a waterproof casing and cooked to 72–74 °C. Most commonly, the all-in method is used for the production of the sausage emulsion itself (see Chapter 12, Section 12.5.2). The cooked and chilled product can be introduced into salami for the purpose of imitating fat. In particular, in chicken salami, such a white-coloured cooked sausage mass finds its use and provides a nice contrast to chicken thigh and/or breast meat.

## 16.2 Selection of additives and starter cultures

Salt is the oldest additive in the world and has been used in the preparation of food for thousands of years. In salami, salt is applied for several reasons. Firstly, salt is the first hurdle against bacterial growth and is applied at levels of between 25–30 g per kilogram of sausage mass. Levels of salt below 25 g per kilogram of salami are not recommended as levels above 25 g per kilogram of salami are significantly more effective in inhibiting the growth of bacteria by reducing the  $A_w$  within the sausage mass. Inclusion levels below 25 g per kilogram of salami are insufficient for development of an effective hurdle against growth of bacteria. The addition of salt at recommended levels lowers the initial  $A_w$  within the salami mass to around 0.96–0.97. Secondly, salt is a flavour enhancer and meat products do not taste good without salt. Thirdly, salt aids the activation of protein which is necessary to obtain slice coherency in the finished product (the salt contributes to formation of a sol during cutting or mixing of the salami mass). The addition of salt

also reduces the temperature of the salami mass by around 1–2 °C. The relatively high level of salt present within the sausage mass reduces the freezing point of water within lean meat to around –4 °C, permitting subzero temperatures within the sausage mass. Therefore smearing of fat is avoided.

The majority of salami, especially all fast- and medium-fast-fermented products, are produced nowadays with added nitrite. Nitrite is another important hurdle against microbiological spoilage especially during the initial stage of fermentation (see Chapter 7, Section 7.2). It is introduced into the sausage mass commonly as sodium nitrite at greatly varying levels depending on the maximum amount permitted in the finished product. Inclusion levels between 150–500 ppm per kilogram of raw unfermented sausage are possible. Around 130 ppm of nitrite per kilogram of sausage mass suppresses the growth of Enterobacteriaceae, such as *Salmonella* spp. and other Gram-negative bacteria. Nitrite plays a major role in controlling bacterial growth in salami manufacture, in particular in fast-fermented salami, when the temperature is raised to between 26 and 30 °C during fermentation. The effect of nitrite as a hurdle against microbiological spoilage is much greater in salami than in other meat products such as cooked ham or cooked sausage. This is because nitrite is more effective at low pH values and acidification occurs during fermentation of salami. In meat products such as cooked ham and cooked sausage, the pH value is raised owing to the addition of alkaline phosphates and the nitrite is not as effective.

Significant amounts of nitrite added to the sausage mass during manufacture cannot be detected analytically just 1–2 days after production, as nitrite react in countless different ways. When additives such as GDL or ascorbic acid are also introduced, it is impossible to detect significant amounts of added nitrite only a few hours after production. Small amounts of nitrosamines as well as secondary and tertiary amines form from nitrite under the slightly sour conditions which exist within salami as a result of acidifying the product. Nitrite is also the primary agent for development of the desired curing colour in a salami and it also contributes to curing flavour. Finally, nitrite also acts as an antioxidant. The antioxidative effect of nitrite comes from the oxidation of nitrite to nitrate. NO obtained from nitrite binds to the iron core of myoglobin and haemoglobin, thus reducing the release of iron, which if not bound would promote oxidation of fat. The binding of NO to myoglobin or haemoglobin instead of oxygen arises because NO has a much stronger affinity to those substances than oxygen has. Nitrite also has the ability to chelate free iron, thus also deactivating this pro-oxidative material.

Nitrate, rather than nitrite, mostly used in the form of potassium nitrate, is added during production of slow-fermented salami. Nitrate does not have a significant impact on bacterial growth. To contribute towards development of curing colour, nitrate has to be reduced first to nitrite before it can bind to myoglobin to form nitrosomyoglobin (see Chapter 7, Section 7.3).

The antioxidants utilized in salami are ascorbic acid, ascorbate, erythorbate and occasionally tocopherol. Ascorbic acid and ascorbate act as direct but

also secondary antioxidants by donating  $H^+$  to the sausage, which deactivates free radicals. In a secondary function they support antioxidative substances such as phenols (which act as antioxidants by absorbing free radicals into their ring-shaped structure), by donating  $H^+$  to phenol radicals for their reduction to phenol. Tocopherols in cured meat products are able to reduce the number of nitrosamines formed and, as tocopherol is fat soluble, it is an excellent antioxidant in slow-fermented salami in terms of retarding rancidity. Reducing the redox potential ( $E_h$  value) within the sausage mass at the beginning of fermentation through the impact of antioxidants is also advantageous for the lactic acid bacteria. This is because competitive microflora, e.g. aerobic bacteria, such as *Pseudomonas* spp., are less able to survive when levels of oxygen are reduced. A reduced  $E_h$  value also makes nitrite more effective as a hurdle against microbiological spoilage. On rare occasions, rosemary extract is utilized as an antioxidant as well.

Ascorbic acid and ascorbate (erythorbate) also act as colour enhancers and are introduced at 0.5–0.7 g per kilogram of sausage mass. Excess levels of ascorbic acid and ascorbate can favour the growth of unwanted bacteria and levels of 0.5–0.7 g per kilogram of sausage mass are fully sufficient. A slightly larger quantity of ascorbate than of ascorbic acid has to be added to fulfil the same function (see Chapter 7, Section 7.4) as a colour enhancer. In the manufacture of fermented salami today, ascorbic acid is commonly used in very-fast-fermented products. In most cases, however, ascorbate, or erythorbate, is applied as it stabilizes the curing colour during the product's long drying period. When ascorbic acid is used, it must not come into direct contact with nitrite within a premix nor be added at the same time as the nitrite to the sausage mass. Ascorbic acid, if used, should be added at the very beginning to the sausage mass. Salt and nitrite are commonly added evenly at the end of the cutting or mixing process.

Spices are introduced into salami according to taste, and care has to be taken as some natural spices may contain a large number of bacteria. Treated spices, with a significantly reduced number of bacteria, should be the preferred choice. Most salamis contain pepper and garlic as their basic flavour. Garlic also has the ability to inhibit growth of bacteria. The amount of garlic that would have to be added, however, for it to have a bacteriostatic effect, would not be tolerated by the consumer.

Other spices commonly introduced are coriander, mace, nutmeg, paprika and chilli. Mustard-powder seed can be added at 1–2%. It reduces the  $A_w$  of the sausage mass, contributes positively to the flavour and delays the onset of rancidity. Mustard powder is made from enzyme-deactivated mustard seed and does not have a mustard flavour as the enzyme responsible for creating the mustard flavour is destroyed during heat treatment. Mustard seed also immobilizes free water as it contains around 25% protein and contributes positively to the firmness of salami. Despite its high level of protein, mustard seed powder is generally declared a spice. Colours such as cochineal are also permitted in some countries but are not commonly applied with salami.

Smoke is an additive commonly applied within the production of salami as it aids preservation (phenols), hardens the surface, acts as an antioxidant, limits growth of unwanted mould and has a favourable impact on colour, flavour and taste (see Chapter 6, Section 6.11). Most countries permit the use of phosphates, which promote easier filling, or better slipping of the sausage mass during filling, reducing the risk of fat smearing and the level added is between 0.2–0.4 g/kg of salami mass.

### 16.2.1 Selection of acidification additives

Most salami, except for slow-fermented salami, acidifies to a greater or lesser extent during fermentation. Certain additives are of great help in achieving a secure and sufficient acidification which has an impact on the colour, sliceability, texture, flavour and microbiological stability of the product.

#### *Glucono- $\delta$ -lactone*

GDL (see Chapter 6, Section 6.15) is the ester of gluconic acid and hydrolyses to gluconic acid once introduced into salami owing to the presence of water, which originates from the meat itself. The addition rate of GDL to fermented salami varies between 3 and 12 g per kilogram of product. Encapsulated GDL can be applied to delay acidification but is generally not applied, as the primary purpose of adding GDL is to achieve fast and secure acidification inside the salami. On an average basis, around 8–10 g of GDL are added per kilogram of salami when acidification is caused entirely by GDL, reducing the pH value from around 5.6 to 4.5–4.7 during fermentation. GDL not only produces gluconic acid but also causes the formation of small amounts of acetic acid. Excess levels of GDL can cause a bitter flavour and the pH value within salami is reduced by around 0.1 pH units (e.g. from 5.6 to 5.5) through the addition of 1 g (or 0.1%) of GDL per kilogram of sausage mass. High levels of GDL also can cause bluish spots on the casing which disappear during the processing steps of fermentation as well as subsequent drying. This phenomenon has as yet not been fully explained.

The transformation of GDL into gluconic acid depends greatly on the temperature of the sausage during the first 24–76 h of fermentation. Higher temperatures during this period of time increase the rate of transformation because any chemical reaction occurs at a faster rate at elevated temperatures. As a rule of thumb, an increase in temperature of 10 °C speeds up a chemical reaction by 100% or, in other words, the same reaction takes place in half the time. Since the formation of gluconic acid from GDL in the presence of water is a chemical reaction, the formation of gluconic acid cannot be stopped as long as there is GDL and free water inside the salami (the formation could in theory be stopped by freezing the product, but this is not an option). Even a reduction in temperature does not stop the formation of further gluconic acid as reduced temperatures only slow the process down. High levels of GDL promote the growth of peroxide-forming *Lactobacillus* spp., which can lead to rancidity and poor curing colour.

*Citric acid*

1 g of citric acid (see Chapter 6, Section 6.16) reduces the pH per kilogram of salami mass by around 0.2–0.3 pH units. The acidification capacity of citric acid is therefore around two to three times that of GDL. However, citric acid is rarely utilized because the rapid drop in pH value allows insufficient time for the development of curing colour as well as curing flavour and contributes to a sour taste in the product.

When the drop in pH value in salami is rapid until the IEP at a pH of 5.2 is reached, its moisture content remains high. If the sol, which is obtained in the salami during cutting or mixing, is transformed quickly into a gel at the IEP, there is little time for water to be removed during the period when the pH value decreases from around 5.7 down to the IEP. The period in which the pH value drops from its starting point down to the IEP at 5.2 is the perfect time to remove high amounts of moisture from a salami. Therefore the level of moisture in the product will be too high, necessitating prolonged drying to obtain the correct weight in the finished product. If the IEP is reached and passed through quickly, the situation is even worse as the water present within proteins becomes bound owing to their rapid denaturation. Only small amounts of moisture are lost until a pH of 5.2 is obtained; drying afterwards is also slowed down and water becomes entrapped in the rapidly denatured protein structures. This is not of economic benefit (see Section 16.3.3).

Occasionally, encapsulated citric or lactic acid is used so that the onset of acidification in the product to be fermented is delayed.

*Sugars utilized for acidification and flavour in salami*

Different types of sugar are commonly used in the production of salami. Their primary function is to provide food for starter cultures and therefore they are fermented into other substances, preferably lactic acid. Added sugar also rounds up and smoothens the flavour of salami and also reduces the  $A_w$  in the product. Therefore it is a minor hurdle against microbiological spoilage.

The decline in pH value in the product depends largely on the type and amount of sugar introduced into salami in the first place. Elevated levels of sugar lead generally to a stronger acidification, and therefore lower pH values. To be fermented into lactic acid, sugars such as sucrose, lactose and maltose must be broken down first into monosaccharide.

Glucose, on the other hand, can be fermented directly into lactic acid. Sucrose is the second-fastest fermentable sugar. Maltose and lactose require a considerably longer period of time for the glycosidic bonds in their molecules to be broken until fermentable monosaccharides are produced. In essence, all lactic acid bacteria can ferment glucose into lactic acid. Sucrose can be fermented by around 85% of lactic acid bacteria, maltose by around 70% of lactic acid bacteria and lactose by only around 55% of lactic acid bacteria. Only around 30% of lactic acid bacteria ferment galactose into lactic acid.

Sugars which are not directly or only partially fermented (e.g. lactose, maltose and galactose in some products) play a role in colour and flavour development.

Generally, 1 g (or 0.1%) of dextrose added per kilogram of salami lowers the pH by 0.1 pH unit. Therefore, 8–10 g of dextrose reduce the pH in salami from around 5.7 to around 4.6–4.8, which is frequently the final pH desired. Similar decreases in pH value can be achieved by adding 7 g of dextrose or 2–4 g of lactose. Sugar does not contribute to the formation of curing colour directly but the fermentation of sugars into acids reduces the pH value within the salami and higher levels of undissociated nitrous acid ( $\text{HNO}_2$ ) are obtained as a result. Increased levels of undissociated  $\text{HNO}_2$  lead to a stronger curing colour (see Chapter 7, Section 7.3). Sugar can also be utilized as food by bacteria such as *Micrococcus* spp., which reduce nitrate to nitrite, also helping to develop a good curing colour. Maltodextrins with a DE value of 20–35 are also used in salami because the presence of different DE values leads to a partial formation of lactic acid, which is desired. When only maltodextrins are applied for the purpose of acidification, significantly higher levels have to be introduced than if glucose were added as maltodextrins have limited acidification capacity. This is rarely the case, because dextrose is such a low-cost material. Sugars or carbohydrates such as maltodextrin, sucrose and lactose not only contribute to the formation of lactic acid but also give a good flavour to the salami. Processing parameters such as different speeds of acidification, the degree or level of acidification and the contribution to flavour overall make it feasible to introduce blends of sugars into salami rather than a single type of sugar.

### 16.2.2 Starter cultures

Salami factories very often develop their own house flora, or factory specific monoculture, over time. When using a house flora to produce fresh salami, however, fermentation is not reliable or consistent. Therefore, for many years, salamis have been inoculated with a concentrated and selected mix of bacteria, or starter culture to begin fermentation. The use of starter cultures means that the proper type of bacterium in the amount required is added to the sausage mass to ensure efficient and safe fermentation. Before starter cultures were used, a back inoculum used to be applied to begin fermentation. The back inoculum was a leftover from a previous fermented batch of salami and used as starter culture for a new batch to increase the number of lactic acid bacteria present in the raw materials. This method of starting fermentation is not practised any longer in modern production facilities. This is because, when a back inoculum is used, all the bacteria present in the inoculum, including the unwanted bacteria such as heterofermentative *Lactobacillus* spp., are introduced into the freshly prepared batch of salami. When larger numbers of unwanted bacteria are present in the inoculum, they automatically contaminate the new batch of product. A new batch of salami produced with a back inoculum is also not fully traceable as a non-standardized material has been utilized.

Starter cultures are selected bacteria which are added to salami for their

positive contribution to acidification (and therefore microbiological stability of the product), colour and flavour. The number of starter cultures added to the salami mass has to be at least  $10^7$  per gram of salami mass and this value shows clearly that raw fermented salami is a living material and millions of bacteria are present within every gram of product. Starter cultures must not be harmful to human health, must be tolerant against high levels of salt as well as nitrite and must work at low temperatures as the salami mass has a temperature around 0 °C after being filled into the respective casing.

Starter cultures are sold frozen, freeze dried or in liquid form and most are non-proteolytic and non-lipolytic. Liquid nitrogen (N<sub>2</sub>) or carbon dioxide (CO<sub>2</sub>) is often used to freeze starter cultures as N<sub>2</sub> has a temperature of around -195 °C and CO<sub>2</sub> has a temperature of around -75 °C. Starter cultures should also not produce CO<sub>2</sub> or hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>) and should grow optimally at temperatures between 22 and 38 °C. When freeze drying starter cultures, water is first extracted using a vacuum. While stored frozen, the cultures are dormant and, once they have sufficient water again, from the meat, they regain their original activity. Freeze-dried cultures can be mixed with cold water 15–30 mm before being introduced into the salami mass to make them faster acting but this is not essential. Premixing with water makes an even introduction into the sausage mass easier as the amount of starter cultures used per batch of salami, without water, is rather small. If premixed with water, demineralized water should not be used as cells would die by bursting in this type of water. The bacteria can, as stated earlier, be premixed with water for around 15–30 min prior to use, rather than for a period of hours as some degree of unwanted activity or fermentation would take place during this period of time. Types of sugar, such as glucose, are predominantly the carriers used in commercial starter cultures and so, if the culture was soaked for too long, it would start to ferment the sugars present.

Around  $10^{10}$ – $10^{12}$  of bacteria are added per 100 kg of salami and these  $10^{12}$  bacteria only weigh around 1 g on their own. Therefore carriers are used as they make starter cultures easier to handle. The number of foreign bacteria within starter cultures should not exceed  $10^3$  per gram of culture and certain bacteria such as *Clostridium* spp. and *Salmonella* spp. must not be present at all.

Starter cultures are introduced into the sausage mass at the beginning of the cutting or mixing process and they must be evenly distributed. Uneven distribution results in non-uniform acidification and therefore faulty products. Nowadays, a mix (or blend) of starter cultures is commonly added in order to fulfil more than one criterion and also so that the culture added is active at a broad range of temperatures and levels of humidity during different stages of fermentation and drying.

Freeze-dried or frozen starter cultures should be stored at a temperature between -18 and -25 °C until use and should not be premixed with other additives such as sugars, GDL, nitrite, ascorbate, spices and salt prior to use. If premixed with other additives 1 or 2 days before being added to the

sausage mass, some moisture is always present and, as soon as the starter cultures have access to humidity, temperature and some food (such as sugars) fermentation would begin and faulty salami would be the result. The acid produced by a starter culture premixed with other additives, even if the premix were stored in a chiller, would be sufficient to react with nitrite and the salami would be discoloured as a result. The acid produced within the premix would subsequently be missing inside the salami and insufficient acidification will take place, leading to microbiological spoilage of the product and a risk of food poisoning. These vital points explain why complete blends or premixes of additives containing starter cultures for the production of salami do not exist. Members of the genera *Lactobacillus*, *Staphylococcus*, *Pediococcus* and *Micrococcus* are important in salami starter cultures. Microorganisms belonging to the family Lactobacillaceae are the most significant in starter cultures in general and bacteria such as *Lactobacillus plantarum*, *Lb. casei*, *Lb. acidophilus*, *Lb. brevis*, *Lb. sake*, *Lb. curvatus*, *Lb. lactis* and *Lb. fermenti* are often used. Commonly, *Lb. plantarum*, *Lb. sake*, *Lb. lactis* and *Lb. curvatus* are used in salami. Lactic acid bacteria are added at levels of  $10^6$ – $10^7$  per gram of salami and homofermentative species are chosen. *Lb. plantarum* ferments a wide range of sugars whilst *Lb. curvatus* ferments mainly sucrose and lactose. *Lb. plantarum* also does not form gas from glucose nor does it reduce nitrate to nitrite. Some strains of *Lb. sake* and *Lb. curvatus* produce  $H_2O_2$  in the presence of oxygen ( $O_2$ ). Lactic acid bacteria in salami starter cultures should be preferably homofermentative (homolactic) and should ferment different sugars predominately (preferably at a level of more than 90%) into lactic acid. Heterofermentative *Lactobacillus* spp., on the other hand, only ferment sugars partially into lactic acid but also into significant amounts of acetic acid, ethanol,  $CO_2$  and  $H_2O_2$ , all substances which are not desirable. If gases such as  $CO_2$  form, pores are produced in the salami or vacuum packages are blown up by the gas. *Lactobacillus* spp. are mostly anaerobic bacteria. They cannot utilize  $O_2$  as a source of energy and therefore produce energy through fermentation. Depending on the type of fermentation taking place, varying numbers of homofermentative and heterofermentative *Lactobacillus* spp. can be found.

The temperature at which *Lb. plantarum* ferments sugar most efficiently is around 35 °C, and such high temperatures during fermentation are applied in a few countries only. *Lb. sake* and *Lb. curvatus* work at lower temperatures, around 26–28 °C. *Lactobacillus* spp. generally do not produce the enzyme catalase even though most of them produce  $H_2O_2$ . *Lb. sake*, *Lb. viridescens* and *Lb. curvatus* are known producers of  $H_2O_2$ , a substance that it is not desirable to produce during fermentation of salami. Different species of *Lactobacillus* added to salami produce sufficient amounts of lactic acid to acidify the salami adequately in a fairly short period of time.

Most lactic acid bacteria produce bacteriocins, proteins or peptides, which are effective against some pathogenic microorganisms. Bacteriocins are not antibiotics but are digested, or broken down, to amino acids in the digestive

system. One strain of *Lb. sake* produces a bacteriocin called saccacin, which is effective against *L. monocytogenes*. *Lactococcus lactis* produces nisin which is effective against *Staph. aureus* as well as *L. monocytogenes*.

Other lactic acid bacteria widely utilized within the production of salami are members of the genus *Pediococcus*. The most common species are *Pediococcus acidilactici*, *P. pentosaceus* and *P. cerevisiae*. *P. acidilactici* ferments sugars most rapidly at temperatures around 40 °C but such a high temperature is rarely used during the production of salami, except in the production of summer sausage in the USA. *P. acidilactici* forms lactic acid from glucose, galactose, arabinose and xylose. *Pediococcus* spp. are generally added at levels of  $10^5$ – $10^6$  per gram of salami. *Pediococcus* spp. introduced into the salami mass die soon after the product acidifies whereas *Lactobacillus* spp. remain alive. *Pediococcus* spp. contribute more significantly to a better overall salami flavour than *Lactobacillus* spp. do, as *Pediococcus* spp. have some proteolytic activity. *P. cerevisiae* grows optimally at 25 °C and its thermal death point is 60 °C. No gas is formed by *P. cerevisiae* when fermenting dextrose and maltose.

Members of the family Micrococcaceae such as *Staph. carnosus*, *Staph. xylosus* and *Micrococcus varians* (now known as *Kokuria varians*), *M. candidus* and *M. aquatilis* are added as starter cultures as well. Most of the *Staphylococcus* spp. and *Micrococcus* spp. added do not produce acid at all. Almost all *Micrococcus* spp. are strictly aerobic bacteria and are only weakly active during fermentation. As they are aerobic bacteria, they cannot act effectively in the core of a salami since there is insufficient oxygen available, or none at all. *Staphylococcus* spp. are aerobic as well as anaerobic and are active in the core of a salami. Because of this, *Micrococcus* spp. are most often added in combination with *Staphylococcus* spp. Adding *Micrococcus* spp. can be advantageous as their nitrate-reducing activity does not depend as much on temperature as that of *Staphylococcus* spp. does.

*Micrococcus* spp. also produce the enzyme catalase and being catalase positive supports the curing colour as well as the aroma of the product and protects the product against  $O_2$ . Micrococcaceae are added at  $10^6$ – $10^7$  per gram of sausage. The enzyme catalase breaks down the viscous  $H_2O_2$  into water and  $O_2$  and therefore neutralizes this highly reactive material.

The presence of  $H_2O_2$  can result in discolouration of the salami as  $H_2O_2$  is a very strong oxidizing agent and can bleach myoglobin, resulting in a green–yellow colour of the salami.  $H_2O_2$  also leads to the formation of radicals and therefore speeds up rancidity. Because catalase breaks down  $H_2O_2$ , rancidity is delayed as well.

*Micrococcus* spp. and *Staphylococcus* spp. generally produce the enzyme nitrate reductase which is of great importance in obtaining and stabilizing a strong curing colour. Large amounts of added nitrite are oxidized to nitrate during the manufacturing process and nitrate would not contribute to colour unless it were reduced to nitrite again by the enzyme nitrate reductase. *Micrococcus* spp. generally do not cause much lactic acid to form and therefore

they should not be applied on their own for purposes of acidification. Often, *Micrococcus* spp. are applied in combination with acid-producing starter cultures. By using this combination, the product acidifies as required and the *Micrococcus* spp. reduce nitrate to nitrite for development of flavour within the product.

*Staphylococcus* spp. are facultatively anaerobic and their metabolism is either respiratory or fermentative. Under anaerobic conditions, they produce lactic acid from glucose whilst, under aerobic conditions, the main products that they produce are acetic acid and CO<sub>2</sub>. *Staphylococcus* spp. grow better under aerobic conditions, however. *Staph. xylosus* shows a wider range of enzyme activity than *Staph. carnosus* and also contributes significantly to development of a good flavour in a salami. Members of both the *Staphylococcus* and *Micrococcus* families cause lipolysis as well as proteolysis to some degree. Lipolysis (breakdown of fat into free fatty acids) and proteolysis (breakdown of proteins into free amino acids) occur during fermentation and drying and are largely responsible for the development of the typical salami flavour. A combination of *Lactobacillus* spp., *Pediococcus* spp. and *Micrococcus* spp. is frequently added in salami as the addition of *Lactobacillus* spp. on their own results in shortfalls in colour, flavour and aroma in the finished product. If *Micrococcus* spp. are added too, they benefit colour and flavour development in fast- and medium-fast-fermented salami.

Countless different blends of starter cultures are on the market today containing a mix of bacteria and these are very often used instead of adding a single species of microorganism. The mixture is chosen based on the fermentation process desired. A distinction is made between starter cultures for fast, medium-fast and slow acidification. Fast starter cultures are used to produce salami, when the pH has to drop to 5.2 (and below) within around 24–48 h. Medium-fast starter cultures are used when the pH needs to drop below 5.2 after around 48–96 h. The starter cultures used for production of slow-fermented salami are most often added as protecting cultures and do not contribute to acidification at all. Their purpose rather is to further development of curing colour and flavour within the product. Generally, a fast drop in pH means that microbiological stability is achieved quickly but the flavour and taste of the product commonly suffer.

### 16.2.3 Selected mould and yeast additives

Yeast and mould are aerobic fungi and can only exist on the surface of salami. Both yeast and mould (noble mould) are introduced to the surface of salami via inoculation. They are either sprayed on to the product or the product is dipped into a solution containing around 10<sup>6</sup>/ml of the mould or yeast.

In terms of the moulds applied, members of the genus *Penicillium* are frequently chosen, e.g. *Penicillium nalgiovense*. In terms of the yeasts used, members of the genus *Debaryomyces* are occasionally applied and *Debaryomyces hansenii* is commonly the preferred choice. *Candida famata*

is another yeast added to salami. Members of these families are chosen as they are salt tolerant but do not reduce nitrate to nitrite.

Yeast requires  $O_2$  for growth and only grows on the surface of a salami. Even slight treatment with smoke kills yeast present on the surface as yeasts cannot tolerate certain components in smoke, such as phenols and organic acids. Yeast and mould protect salami against the influence of  $O_2$  and stabilize the colour. Exposing the surface to less  $O_2$  and light also slows down development of rancidity. Finally, formation of a dry ring, or case hardening, is avoided as the layer of yeast or mould protects the surface from excessive drying out.

Some strains of *Debaryomyces* are very tolerant against a low  $A_w$  and even grow at an  $A_w$  of 0.86. There is evidence that *D. hansenii* inhibits growth of *Staph. aureus*. *D. hansenii* helps the development of a stable and strong curing colour as well as the development of the typical salami flavour inside the salami and is occasionally directly added into the sausage mass at around  $10^6/g$  of sausage mass. *D. hansenii* neutralizes lactic acid and contributes to a milder flavour. It also supports the breakdown of protein into peptides and amino acids through proteolysis and the formation of free fatty acids through lipolysis, contributing to formation of a good flavour.

Moulds such as *Penicillium* spp. cause a white or grey–white mycelium to grow on the surface of salami. Generally, conidia on salami should not be green, black or yellow in colour. Mould present on the surface of salami keeps away  $O_2$  and therefore stabilizes curing colour inside the salami. Mould also contributes to the development of the typical salami flavour as it contains proteases and lipases which break down proteins and fats into components such as amino acids and fatty acids. In addition the presence of the layer of mould on the surface also slows down development of rancidity as it protects the salami from the impact of  $O_2$ , as mentioned above, and also light. The layer of mould also slows down the loss in weight during drying of the product and minimizes the risk of obtaining a dry ring (case hardening).

Moulds commonly added are *P. nalgiovense* and *P. candidum*. Neither of these produce any mycotoxins and all surface moulds applied to salami must be non-toxic. The colour of the conidia and mycelia growing on the surface of the product must be white or grey–white in colour. Surface mould must grow quickly, cover the sausage uniformly (within 3–5 days) and develop a specific and consistent flavour. The added mould also must not contain any enzymes active on cellulose as these would literally ‘eat’ up fibrous casings. Non-waterproof casings are used for products with surface mould. Most of the casings chosen have a rough surface for the mould to cling on to, which makes them grow well. Occasionally, the fully dried salami is rolled in talcum powder at the end of the drying process to compensate for uneven growth of mould during drying.

#### *Prevention of unwanted mould*

Unwanted mould can cause a series of problems in the production of salami.

While surface mould is white or grey–white in colour, unwanted mould can be a wide range of colours and is often black, green or even yellowish. The major cause for growth of unwanted mould is having a high RH for too long a period of time at the initial stage of fermentation and/or the application of smoke too late in the production process. If these conditions occur, generally, mould starts to grow on salami after around 3–4 days during the initial stage of fermentation. Airflow has an impact on mould growth as well and, if airflow is too slow, mould growth increases. Growth of mould also occurs during drying of products, once again usually because the RH is too high and the airflow is too slow. Drying rooms should be free of mould as mould here would inoculate mould-free products and spread the problem around.

Besides being not attractive to the human eye and producing a bad smell, quite a few species of unwanted mould produce different mycotoxins, which penetrate into the product. Therefore, the removal of unwanted mould from the surface of the salami only removes the visible part of mould: the mycotoxin is still present inside the salami. Proteolytic mould can cause a sausage casing to deteriorate entirely. Black spots can be occasionally seen on the surface of a salami just underneath the casing as a result of the presence of unwanted mould. Mould can grow as O<sub>2</sub> is present in these areas just underneath the casing.

The two common ways of preventing growth of unwanted mould are to apply natamycin or potassium sorbate to the salami. However, it is best to avoid growth of unwanted mould during the initial stages of fermentation in the first place, mainly by controlling the RH during all stages of fermentation and drying and applying smoke at the correct time. Growth of unwanted mould can be fought successfully using natamycin, an antifungal produced by *Streptomyces natalensis*. Natamycin forms a complex with the steroids found in moulds and yeasts and destroys their cell membrane. As a result, permeable cell membranes permit cations and other ions to penetrate into the mould cell, making its pH drop rapidly, and ultimately the cell dies. A major advantage of natamycin, compared with potassium sorbate, is that it does not penetrate into the sausage mass at all and therefore has no impact on fermentation, colour or flavour development, especially in the outer layers of the product. Steroids are not present in bacteria which means that natamycin has no impact whatsoever on the bacteria present in salami. It has no impact on the starter cultures added and the entire fermentation process is not influenced in any way. There are a few products on the market containing natamycin. In most cases, 5–7 g of a commercial product are mixed with 1 l of warm water, well stirred and then left standing for around 30 min. During this time the mixture will thicken slightly. Around 8–10% of salt are added afterwards and this final mixture can be sprayed on to the salami or the freshly filled salami can be dipped once into this low-viscosity slurry. Experience shows that natamycin is several times more effective than potassium sorbate.

Another option to prevent the growth of unwanted mould is to apply potassium sorbate. The filled salami can either be dipped immediately after

filling into a 10–15% potassium sorbate solution or be sprayed with this solution 1–2 days after fermentation has commenced. Most commonly, the filled salami is dipped into the solution for a few seconds and spraying is not commonly practised. Alternatively, the casing used can be soaked in water containing sorbate before being filled. Several food standards in the world have a set maximum level of residual sorbate within the outer layers of raw fermented salami, and the strength and duration of the dipping solution as well as the actual dipping process has to be adjusted in accordance with the maximum levels in the finished product. The disadvantage of using sorbate is that it penetrates into the outer layers of the salami and can interfere with fermentation and cause discolouration.

Mould normally grows at RH levels above 75% at warm temperatures and low air velocities, speeding up growth. High levels of humidity favour the growth of black moulds and proteolytic moulds, which ‘eat up’ casings. If unwanted mould is present in fermentation or drying rooms, they should be cleaned with an alkaline cleaning detergent as acid-based cleaning materials are not as effective as alkaline materials against moulds. Once the room is properly cleaned and rinsed, a solution containing 5–7% of potassium sorbate can be sprayed all around it. The sprayed room is then left standing to dry completely and the sorbate solution is not washed off. Finally, all the tools used during cleaning should be disposed of as they would cause regrowth of mould if they were used again. Salami affected by growth of mould can also be washed with a salt or lactic acid solution and cold smoked once it is dry again to remove unwanted mould (if the product is not smoked afterwards, then the mould grows again and is only removed for a couple of days). However, as stated earlier, growth of unwanted mould should be avoided initially as this makes labour-intensive steps such as washing unnecessary. Vacuum packing of the finished product or an RH below 75% during drying suppresses growth of mould during storage.

## **16.3 Manufacturing technology**

During manufacturing, the carefully selected raw materials are combined with the chosen additives to create a safe, tasty and strong coloured end product with good slice coherency. Modern technology facilitates the production of a perfect salami, but experience and sound knowledge of the cutting, mixing, fermentation and drying process are still of great help.

### **16.3.1 Salami made in a bowl cutter**

Salami with a particle size of 0.8–3 mm is commonly produced in a bowl cutter. The bowl cutter must not be rusty as any rust introduced into the salami mass interferes badly with fermentation and colour development. The bowl cutter must also have been cleaned properly the previous day as rapid

bacterial growth would have taken place in any particles of sausage remaining in the bowl cutter and all those bacteria would subsequently be introduced into the new batch of salami. In addition, no traces of cleaning and/or disinfection materials must be present on the machine as they can interfere badly with fermentation.

The knives of the bowl cutter should be sharp as a clear cut is desired, and smearing of fat and meat during the cutting process is to be avoided; smearing of fat causes major problems during fermentation and drying of the product. The sharpening angle of knives utilized for cutting salami should be around 22–25° (a small angle produces a sharp knife). The knives also have to be adjusted so that the distance between the end of the knives and the bowl of the bowl cutter is a maximum of 1–2 mm. The number of knives present varies between three and six but three knives is the norm. Some models of bowl cutter permit the use of six knives, however, without any increased risk of fat smearing. Bowl-cutter knives rotate at around 55–70 m/s during cutting and are slowed down to around 3–5 m/s during mixing. Special salami bowl cutters are on the market which have two sets of knives. These double cutters have the advantage that the salami mass is cut twice during one turn of the bowl and the desired granulation is reached quickly. Obtaining the desired particle size in a short period of time lowers the risk of smearing of fat once again and more batches of product can be produced within a certain period of time, which is economically beneficial.

In general, the bowl cutter should be around half-full during cutting of the meat and fat materials to ensure a proper flow of material to be cut. Overloading of the cutter leads to jamming and the materials are not cut cleanly. Jamming also increases the temperature of the mass, rapidly resulting in an enhanced risk of fat smearing. Fat and meat materials are generally cut at a medium–fast knife speed at around 2000 rev/min, or 55–70 m/s (slower than during the production of an emulsion by cooked sausages) and the bowl speed is fast to ensure that the materials to be cut flow ‘freely’ through the cutter. During mixing of the mass in the final stage, the knife speed is reduced drastically to around 3–5 m/s or around 300–500 rev/min.

Several different methods of cutting a salami in the bowl cutter are commonly practised.

- 1 Hard frozen fat, and here primarily pork back fat, is cut with the frozen meat cutter and placed in the bowl cutter. A small amount of lean minced meat is added to it and the fat is cut for a while until a granulation of around 8–10 mm is obtained. The reason for cutting fat first for a while on its own is that frozen fat seems to ‘move away’ from the rapidly turning knives and, if fat and meat are added at the same time, the meat is more finely comminuted than the fat. The addition of some chilled minced meat to the fat at the beginning of the cutting process holds the fat together; cut pieces of frozen fat on their own have a tendency to move uncontrollably within the bowl during cutting. Semifrozen meat is added afterwards to the cutter and additives such as starter cultures,

spices and colour enhancer are added evenly whilst cutting under a medium–fast speed. Hard-frozen meat is not used as it is very harsh on the knives. If this type of meat were cut, they would need to be resharpened very often. Preconditioned meat, as described in Section 16.1.1, demonstrating a temperature of around  $-2\text{ }^{\circ}\text{C}$  is commonly added as well. All additives as well as starter cultures have to be added evenly during cutting as a batch of salami experiences significantly less cutting and mixing than, for example, a batch of finely cut emulsified sausage. Unevenly introduced additives, especially starter cultures, are commonly the cause of faulty salami and a lack of fermentation can be the result of such inaccuracy. Once the desired granulation, or particle size, is obtained, the knife speed is reduced to around 200–300 rev/min and salt as well as nitrite are evenly introduced to guarantee even and secure colour development. The salami mass is just gently mixed afterwards until the salami mass is slightly tacky and a small degree of protein is activated by the presence of salt. This tiny amount of activated protein is a ‘sol’ (a solid dispersed in a liquid) and consists of salt, activated protein and water (from the meat itself). The sol is needed for slice coherency during fermentation as well as subsequent drying and it is a colloidal system where particles within are still moving freely. A ‘gel’, in contrast, is a solid substance in which particles do not move freely. The finished salami mass should be at a temperature of between  $-4$  and  $-1\text{ }^{\circ}\text{C}$  and a combination of fully frozen fat, semifrozen meat and preconditioned meat is selected so that the salami mass ends up in this temperature range. When no preconditioned meat is available, then frozen meat is tempered so that a combination of frozen fat and tempered meat results in the same temperature within the finished salami mass.

- 2 Another method of cutting salami is to work with frozen fat as well as with semifrozen meat. The frozen fat is cut first for a few rounds before the semifrozen meat is added. All additives excluding salt and nitrite are evenly added, and the fat and meat are cut until the desired granulation is reached. At this point, salt and nitrite are evenly introduced as well as around 10% chilled minced (2–3 mm) lean meat. The entire mass is mixed until it is slightly tacky. Working with frozen fat as well as semifrozen meat has the advantage that there is no risk of smearing. However, a sausage mass cut by this method is at a temperature of around  $-10\text{ }^{\circ}\text{C}$  after cutting, which is too cold for the activation of some protein and therefore no binding within the sausage mass occurs. Chilled minced meat is therefore added at the end of the process to raise the temperature of the mass to between approximately  $-4$  and  $-1\text{ }^{\circ}\text{C}$ , which allows some activation of protein and the formation of a sol.
- 3 Yet another method of cutting salami is to combine frozen fat, semifrozen fatty meat material and some chilled meat in the bowl cutter at the same time and to commence cutting at a medium–fast speed. All additives including starter cultures except salt and nitrite are added evenly into the

sausage mass right at the beginning of the cutting process and all the sausage mass is cut until the desired granulation is reached. At this point, salt and nitrite are added evenly and the materials are mixed for a short while until some sol is obtained and the mixture is slightly tacky. Experienced producers of salami have worked out the ratio of frozen, semifrozen and chilled material needed to obtain a final temperature of between  $-4$  and  $-1$  °C in the salami mass. Generally, the addition of salt at the end of the cutting process reduces the temperature of the entire sausage mass by around 2 °C. Even though the temperature is as low as  $-4$  °C, the water in meat does not freeze again because of the fairly large amount of salt added to the sausage mass (25–30 g per kilogram of sausage mass). The added salt lowers the freezing point to around  $-4$  °C. Temperatures below  $-4$  °C would cause the water to turn into ice and no sol would form, resulting in poor slice coherency. Pores would also be present in the finished product.

During all these different cutting methods, the coldness drawn from semifrozen meat materials helps in the cutting of fat; the surface of the cut fat remains frozen owing to the presence of the semifrozen meat.

Pure-beef salami is commonly produced from fatty beef brisket and the meat material is utilized in a semifrozen state and cut until a particle size of around 2–3 mm is obtained. All additives except salt and nitrite are added during the initial stage of the cutting process. Salt and nitrite are added at the end of the process and a final temperature of the sausage mass between  $-4$  and  $-1$  °C is desired.

As a general rule, the finished mass of a finely cut salami should be slightly tacky once removed from the cutter. The temperature of the mass should be between  $-4$  and  $-1$  °C once the cutting process is completed to eliminate the risk of fat smearing during cutting. Salamis with a smaller particle size (1–2 mm) should have temperatures between approximately  $-3$  and  $-4$  °C whilst salamis with larger particle sizes (3 mm) can have temperatures between approximately  $-3$  and  $-1$  °C. In any case, the temperature of the sausage mass should not be above 0 °C. Superfine-cut salami, with a particle size of around 0.8–1.0 mm is cut using dry ice (CO<sub>2</sub>). The dry ice is gradually added to the bowl cutter during cutting to keep the temperature of the mass below 0 °C during the prolonged period of cutting. This is so that small particles are produced without fat smearing. Once the desired granulation is reached, salt and nitrite are evenly mixed into the sausage mass until some degree of binding takes place (i.e. a sol forms) and the final temperature is between  $-4$  °C and  $-1$  °C.

CO<sub>2</sub> is 1.5 times heavier than air and is a linear molecule. It condenses under normal pressure directly into a solid at around  $-78$  °C and this solid is known as dry ice. Solid CO<sub>2</sub> does not melt under normal atmospheric pressure but sublimates directly into a gas (sublimation is a process where a substance turns from being solid directly into a gas without having been present as a liquid). Liquid nitrogen can be utilized for cooling purposes as well but the

introduction of nitrogen into the salami mass has to be tightly controlled as nitrogen has an enormous cooling capacity and incorrect introduction of nitrogen into the salami mass can reduce the overall temperature of the sausage mass easily to levels of between  $-10$  and  $-15$  °C.  $N_2$  is made from liquefied air and has a boiling temperature of  $-198$  °C. During evaporation, large amounts of heat are removed and  $N_2$  is an inert gas, meaning that it does not react with any component within the sausage mass.

Smearing of fat has to be avoided during cutting as this would block capillaries in the sausage mass and subsequent drying would be badly affected. The period of time between obtaining the finished mass in the bowl cutter and filling of the salami should be as short as possible. If a batch of salamis is unloaded into a trolley and left standing for an extended period of time, the internal temperature will decrease even further and can drop below  $-5$  °C. If that is the case, the water in muscle tissue turns into ice. Pores will therefore be seen in the final product and the filling process will be very difficult to achieve. The semifrozen sausage mass has to be mixed again in the cutter to raise the temperature in order to remove possible lumps of frozen material within the sausage mass. Generally, the person working the bowl cutter should work at the speed at which the products are being filled so that the sausage mass does not rest for a long time before filling. If the sausage mass is frozen on filling, the vacuum applied does not remove entrapped air properly and therefore there will be pores in the final product. The application of a slight vacuum during the final mixing stage of the cut sausage mass is advantageous as more sol is obtained which benefits sliceability in the final product. As  $O_2$  is removed, development of the curing colour is enhanced and the  $E_H$  value is reduced within the sausage mass as well. Reducing the  $E_H$  value provides aerobic spoilage bacteria such as *Pseudomonas* spp. with less  $O_2$ , thus inhibiting their growth.

#### *Salami made with a mincer–mixing system*

Salamis with a particle size of 4–13 mm (or larger) are generally produced by mincing the meat and fat materials and then mixing them properly. Pure-beef salami, predominantly made from fatty beef briskets, can be produced in this way as well. If a bowl cutter is available, all the meat and fat materials are placed in the cutter and cut up for only a few rounds to obtain pieces of meat and fat which can subsequently be minced. During the few rounds of cutting (which is performed at a slow knife speed), starter cultures (if used) are evenly mixed into the sausage mass. The temperature of the sausage mass at this point is between approximately  $-2$  and  $0$  °C. A combination of frozen, semifrozen, preconditioned and occasionally chilled materials are used to obtain the desired temperature overall. After removal from the cutter, the mass is minced with a blade which produces meat and fat particles of a diameter between 4 and 8 mm. It is vital that mincing is carried out without any fat smearing taking place and that cleanly cut particles of meat and fat are obtained.

The minced materials then drop on to a belt. All other additives such as spices, colour enhancer, nitrite and salt are added by being dropped on to the minced materials from a dispenser placed above the belt as the materials pass by. The belt leads to a mixing device, and the minced materials and the additives on top of them drop into this mixing device which has several small fast-rotating arms. The whirling action of the rotating arms distributes all the additives well among the minced meat and fat material. The material is then placed into a paddle mixer for final mixing. Final mixing takes place gently for a short period of time to distribute all additives evenly and to obtain a sol to some degree. It is also helpful to apply a vacuum during the final mixing stage to remove trapped air. This makes colour development take place faster and the  $E_H$  value is reduced as well.

Large processors of minced salami operate fully automated lines in which frozen and semifrozen materials are cut with a mincer into particles of around 13–20 mm diameter and then drop into a large-paddle mixing machine. All additives are added and the mass is mixed for a short while. The mixed materials drop on to another belt and are then transported to the mincer where final mincing takes place. The minced materials drop on to another belt which loads a paddle mixer within which final mixing takes place. In some cases, the mass drops from the belt on to a whirl mixer before landing inside the final mixer.

Another method of producing minced salami is to place all the materials in the bowl cutter, to put in all the additives (and starter cultures) and then to cut the materials under a slow knife speed until minceable pieces of meat and fat are obtained. The coarse sausage mass is removed from the cutter and minced with the desired blade. Following mincing (which should be carried out without causing smearing), the mass is mixed in a paddle mixer until some degree of tackiness is seen. Paddle mixers are used as they do not cut the individual particles of meat and fat any further and produce an efficient gentle mixing action. As stated above, a long resting time between mixing and filling should be avoided. The advantage of producing salami with a mincer is that all meat and fat particles are of exactly the same size, which is not the case with salami cut in the bowl cutter.

### 16.3.2 Filling

Filling should take place immediately after the sausage mass is produced as long resting times lead to a decrease in temperature within the salami mass and the appearance of hard lumps owing to the formation of ice. The cut or minced–mixed salami mass is filled into permeable casings. Fibrous and collagen casings are most commonly chosen. Salamis filled into natural casings have a very attractive old-world appearance, but care must be taken that the natural casings have a low bacteria count and that all adherent fat has been removed as the salami would otherwise become rancid quickly. Natural casings, besides their attractive appearance, protect the sausage more effectively against

case hardening than fibrous and other types of casing do, because they contain a fair amount of fat and connective tissue which acts a moisture buffer.

All casings used, regardless of origin, should be treated in the correct way to ensure maximum functionality of the casing. It is important that the casing is filled to the desired diameter, shrinks with the product during drying and clings to the product in the desired way. Some fibrous casings used today contain antimould substances such as food acids and sorbate which reduce the risk that unwanted mould might form during fermentation and subsequent drying. Salami should never be filled into waterproof casings as no smoke would penetrate through the casing on to the product. The product would also not dry, the process during which moisture is removed from the salami. Some salamis are filled into moulds of triangular or other shapes. These moulds have to be lined with a breathable foil first so that the sausage mass does not stick to the mould. Without the foil, subsequent removal of the sausage from the cage, or mould, would be impossible.

The sausage mass at point of filling should have a temperature between  $-4$  and  $0$  °C depending on the particle size to avoid fat smearing during filling. Fat smearing creates a thin layer of fat underneath the casing and drying is badly affected as capillaries are closed by the layer of fat. In extreme cases, drying can be inhibited altogether by fat smearing. A high  $A_w$  for a long period of time in the core of the salami can lead to microbiological spoilage as unwanted bacteria such as *Salmonella* spp. have prolonged access to free water until the  $A_w$  drops to 0.95, the  $A_w$  by which growth is inhibited. If the sausage mass is at temperatures below  $-4$  °C, it is extremely hard to handle for the filling machines. A proper vacuum also cannot be applied during the filling process at temperatures below  $-4$  °C owing to ice formation within the salami. Therefore pores, or small air pockets, can be seen in the final product.

The filling speed should be moderate as fast filling speeds increase friction within the sausage mass while it passes through the filling horn (stuffing pipe). This increases the risk of fat smearing. A filling pipe of the largest possible diameter should be used as a large diameter lowers friction in the sausage mass as the mass passes through the pipe. The filling pipe should also be as short as possible to reduce the degree to which the sausage mass is squeezed as it passes through the filling horn.

Generally, salami is filled tightly into casings and creating a vacuum during filling is of great benefit. Owing to the absence of  $O_2$ , a better curing colour is obtained and the reduced  $E_H$  value gives unwanted aerobic spoilage bacteria less chance to grow. A more compact sausage is obtained if a vacuum is created during filling and no pores are therefore visible in the finished product. Large amounts of  $O_2$  are introduced into a salami mass whilst it is mixed in the bowl cutter or mixing machine and high levels of oxymyoglobin form. In fast-fermented salami, the oxymyoglobin (especially in small-diameter products) is liable to denature and this results in an atypical colour in the finished product. If  $O_2$  is removed during filling, this aids the formation of

nitrosomyoglobin, which helps to avoid this problem. Modern filling machines redirect the sausage mass very little during the actual filling process, which is a great advantage. Older-style filling machines usually redirect the sausage mass and this increases friction and therefore the risk of fat smearing in the sausage mass is greater. Occasionally, the salami mass is filled first into cylindrical barrels and then the filling horn is attached to the front of the barrel. The sausage mass is pushed from the opening at the other end of the barrel towards the filling horn. This means that the sausage mass is not redirected during filling, which reduces the risk of fat smearing. This process takes place under a vacuum.

Some filling machines are combined with a mincing device and so mincing and filling take place at the same time. The salami mass is prepared first as described above; meat and fat particles of a size between 13 and 20 mm are mixed in a paddle mixer and all additives (including starter cultures if used) are added until the mixture is slightly tacky; the temperature of the mixed mass is between approximately  $-3$  and  $-1$  °C after mixing is completed. This mass is placed into the filler's hopper and the sausage mass passes through a mincing device, which is placed just before the filling horn. As a result, the coarse meat and fat particles are minced and then pass through the filling pipe into the casing in one processing step. It is essential, however, that the mixed mass that is loaded into the filler is evenly mixed as only a small amount of mixing takes place during the final mincing and filling stages. This second mixing step cannot compensate for any uneven mixing in an earlier processing stage. An unevenly mixed sausage mass would result in faulty products as additives such as salt, nitrite and starter cultures are not evenly distributed throughout the product. Insufficient amounts of salt, nitrite and starter cultures result in poor curing colour and a lack of effective hurdles against microbiological growth. This means that the fermentation process could go out of control or might not take place at all.

The surfaces of working tables and benches used during filling must be clean as any contamination would lead to defects in the product to be fermented such as poor curing colour, discolouration, microbiological spoilage and growth of mould. Sausage mass produced with GDL must not be left for a long time before filling as acidification starts as soon as GDL comes into contact with water from meat. The transformation of GDL to gluconic acid is a chemical reaction and the formation of gluconic acid causes the pH to drop. Once the pH value of the sausage mass drops below 5.2 (which mainly happens on the surface of the sausage mass placed in trolleys as the surface is warmer than the core), the sol is transformed into a gel which is then destroyed during filling. Once a gel is destroyed, it will not form again and poor slice coherency will be the result. Under no circumstances must an unfilled salami mass, produced with GDL or fast-acting starter cultures, be placed in the chiller overnight or be left standing anywhere else. If this occurs, the pH value within the entire sausage mass could drop below 5.2 and all sol would be transformed into gel before the product finally was filled into its casing.

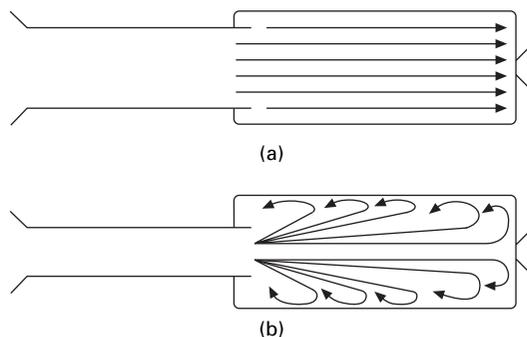
Cupping is a commonly observed problem in small-diameter pizza salami. This is when the outer areas of a slice of salami move away from the pizza under the severe impact of heat in the pizza oven, but the centre remains attached to the pizza, forming a cup shape. This problem can largely be prevented by using the largest filling pipe possible for the respective casing and by filling the salami mass straight into the casing, avoiding back rolling. To be more specific, the salami mass should not be redirected in any way as it is filled into the casing. When a small-diameter filling horn is used to fill a casing of a much larger diameter, the sausage mass curls back and is mixed up again, which leads to cupping on the pizza. When filling all types of salami, the largest filling pipe possible for the chosen casing diameter should be used.

Figure 16.1(a) illustrates use of a wide filling horn. Using a small-diameter filling horn (Fig. 16.1(b)) causes the salami mass to be redirected (curling back).

### 16.3.3 Fermentation and drying

Fermentation is the process in which the raw and microbiologically unstable sausage mass turns into a shelf-stable product with strong curing colour, good sliceability, pleasant flavour and most importantly microbiological stability. A raw fermented salami can be made microbiologically stable in two ways: firstly, by having an  $A_w$  of or below 0.89 (via drying) or, secondly, by having a pH value below 5.2 (via acidification). In some salami produced, both hurdles to ensure micorbiological stability are in place at the same time, which makes the product particularly safe. One hurdle, however, is sufficient to control bacteria such as *Salmonella* spp. and *Staph. aureus*, which are the greatest hazards in salami. Food standards in some countries demand a decline in pH value below 5.2 within 48 h to reduce the risk of growth of *Salmonella* spp. and other bacteria such as *L. monocytogenes*.

Products made from pork and beef, or only pork, ferment more quickly



**Fig. 16.1** (a) A large-diameter filling horn; (b) a small-diameter filling horn, resulting in 'back curling' of the salami mass.

than products containing only beef. This is because pork usually contains more lactic acid than beef, and beef generally has a higher initial pH value than pork as well. Beef also generally has a larger buffer capacity, which reduces total acidification during fermentation. The level of fat present within the product also plays a role in fermentation. Salami with a lower fat content automatically contains elevated levels of lean meat. An increased level of meat within the product raises the level of water and therefore the  $A_w$ . As a result, more water is available to bacteria such as *Lactobacillus* spp., fermentation is prolonged and the pH value drops slightly lower (and faster) than it would do in a fattier product, with less free water. The underlying theory here is that the activity of most lactic acid bacteria stops at an  $A_w$  around 0.95. If the  $A_w$  of the salami mass is above that value for a longer period of time, bacteria that cause acidification will be active for longer. In addition, it is usually stated that increasing the amount of lean meat in the sausage mass results in higher levels of glycogen and this also leads to a greater degree of acidification. It may be the case, however, that increasing the level of lean meat also increases the buffer capacity of proteins and more sugar, or GDL, has to be added for the desired drop in pH to take place. On the other hand, elevated levels of fat reduce the  $A_w$  of the freshly produced sausage mass and the RH has to be higher during fermentation, especially within the first 24–48 h, to avoid case hardening.

During fermentation and drying, the conditions in the smoking chamber or drying room such as the temperature, air speed (i.e. the speed of the airflow) and RH greatly determine the reactions inside a salami. The conditions in the salami, in turn, determine factors such as the colour and colour development, texture, weight loss, flavour and microbiological stability of the product. The fermentation room should be free of mould and clean before it is loaded with freshly filled salami. Salami generally have an  $A_w$  of 0.96–0.97 when they are filled. ‘Greening’ and ‘maturing’ are other terms used interchangeably with fermentation although greening more specifically can describe the first 48–76 h of fermentation until the pH value has dropped to the desired level. After fermentation, drying is the next step.

Fermentation should only commence once the fermentation room has been loaded to ensure that all freshly filled products are exposed to the same climatic conditions right from the start. The filling, or loading, of a fermentation room (depending on its size and how fast trolleys are placed into it) can last for hours. There should also be no airflow during loading of the fermentation room as prolonged periods with airflow at an RH around 75% can create case hardening before fermentation has even started. Only once the fermentation room is full, or when production of salami has finished and all the product has been loaded into the fermentation room, can the fermentation programme begin.

The filling level of the room also has a significant impact on fermentation and drying of salami. The room should not be overloaded as there must be a uniform airflow all the time for optimal drying and to prevent growth of

mould. If the fermentation or drying room is only partially filled, parameters such as the temperature, RH and air speed have to be adjusted to avoid case hardening. If the fermentation room is only half full, case hardening occurs more easily as there is a greater volume of air available to remove moisture from a smaller surface area of salami. A standardized fermentation and drying programme can only be followed if the room is always filled to similar levels and the product itself always has similar particle sizes and is filled into casings of similar diameters. As soon as one of these three factors changes significantly (degree of room loading, particle size of meat and fat materials, and diameter of casing), the fermentation programme has to be adjusted. Varying levels of fat within a product caused by a change in recipe also need to be taken into account. Higher levels of fat reduce the starting  $A_w$  of a product whilst a reduction in fat increases the  $A_w$  of the product.

Fermentation starts by raising the temperature and moisture level and increasing the airflow. These three different parameters vary based on the type of salami (e.g. fast-, medium-fast- or slow-fermented salami). During the first 1–6 h of fermentation, fast- and medium-fast-fermented salamis experience an RH of around 60–70%, a temperature between 16 and 22 °C and an air speed of around 0.8 m/s. The time span of 1–6 h is known as the conditioning time and its length depends largely on how full the fermentation room is and the diameter of the product. When the room is full and for large-diameter casings (e.g. 90 mm), the conditioning period can last up to 6 h. On the other hand, if the room is only half full and sausages filled into a 45 mm casing are placed in the room, conditioning might last for only 1–2 h. It is virtually impossible to give exact guidelines as different fermentation rooms work differently and experience is very important here.

As the cold salami (around 0 °C) is placed into a significantly warmer environment, condensation water forms on the surface of the salami and is removed during conditioning (see Chapter 4, Section 4.12). Conditioning is a very cost-effective way to remove moisture from a salami. There is no need for the RH to be high during conditioning, contrary to the other stages of fermentation, as condensation water produces 100% moisture on the surface of the freshly filled salami in any case. The unnecessary addition of moisture would not economically be of benefit. Myoglobin would also be washed out from the surface of the salami, contributing to a weak curing colour in its outside layers.

Conditioning lasts just long enough for no more condensation water to form on the product and must also end before case hardening occurs. Temperatures of only 16–22 °C are used, rather than 26 °C or higher, so that temperature is a hurdle against microbiological growth.

The reduction of free water also reduces enzyme activity and this can present problems, especially in small-diameter products. If small-diameter products (20–28 mm) are dried too quickly during the first stage of fermentation, the  $A_w$  in the outside layers of the product is reduced to a level which is too low for *Lactobacillus* spp. to act ( $A_w$  below 0.95). The pH value on those

outside layers of the product remains at around 5.5 as acidification never takes place. Only very little curing colour develops, or possibly none at all, and the low  $A_w$  on the surface finally denatures mostly metmyoglobin and the final product is of a very poor grey colour.

Therefore, when producing small-diameter products, in order to maintain an  $A_w$  above 0.95 for a sufficient period of time for the *Lactobacillus* spp. to work and to reduce the pH value within the outer layers of the product thus supporting the formation of curing colour, there is no conditioning phase. Fermentation of small-diameter products starts at around 93–95% humidity in order not to reduce the  $A_w$  on the surface too rapidly.

Once conditioning of larger products is completed, the level of RH within the chamber is raised to 90–93% and the temperature is increased to around 22–26 °C. During this period, enough moisture has to be provided to allow starter cultures to grow and produce lactic acid but the product must also dry at the same time. The air speed is high (around 0.8 m/s) to remove moisture from the surface of the product. Temperatures of 22–26 °C provide the perfect climate for starter cultures to grow and, in combination with high levels of moisture, production of lactic acid is ensured. The temperature range is wide as the temperature used depends on the speed at which the pH value should decrease in the product and whether fast- or medium-fast-acting starter cultures are being used. From a microbiological standpoint, temperatures above 26 °C are not recommended. If these temperatures are used, it is slightly risky as nitrite is therefore the only hurdle in place against microbial spoilage during this stage and the usage of meat and fat material displaying a low bacteria count is critical. However, temperatures of 26–28 °C are commonly used in the fermentation of fast-fermented salami.

The level of RH in the fermentation room is based on the  $A_w$  within the salami. Generally, the level of RH in the room should be 2–5% lower than the  $A_w$  within the sausage: the difference in moisture levels ensures fast drying without the development of case hardening. The difference between the moisture levels in the fermentation room and the sausage depends greatly on the diameter of the casing used as well as on the particle sizes of meat and fat. Moisture can be removed more quickly in small-diameter sausages containing coarse particles of meat and fat than in large-diameter products exhibiting small particles of meat and fat. In small-diameter sausages, the distance between the core and the surface is significantly shorter than in large-diameter products. During the production of coarse minced-mixed salami, less protein has been activated than in a finely cut salami and water is only loosely bound. In small-diameter salami made from coarse particles of meat and fat a difference in moisture level of 4–5% can be tolerated whilst in large-diameter and finely cut salami the difference can only be 1–3%. In particular, in superfine salami, cut with the help of dry ice (CO<sub>2</sub>) the difference is commonly only 1–2% to avoid case hardening. The formula applied to calculate the correct level of RH inside the fermentation room is  $(A_w \text{ of sausage} - D) \times 100$  where  $D$  is the difference, having a value between 2 and

5. As an example, a finely cut freshly filled salami in a large casing might have an  $A_w$  of around 0.97 at the beginning of fermentation. As a result, the RH inside the room once the period of preconditioning is over should be 94–95%, which represents a difference in moisture levels of 2–3%. When a small-diameter casing is used and the salami is made from coarse meat and fat particles, the level of moisture inside the room can be 91–92%, which is a difference of 4–5%. This difference in moisture levels should be maintained all the time for drying to take place as quickly as possible without the occurrence of case hardening. The products are then placed in the drying room for the final drying stage.

At the beginning of fermentation, bacteria such as *Pseudomonas* spp. and Enterobacteriaceae are regularly present in the sausage. As acidification starts to take place, the numbers of these bacteria should decrease within 1–2 days whilst lactic acid bacteria grow rapidly and come to dominate the internal microflora. During the initial stages of fermentation, the primary hurdles against microbial spoilage are the low bacteria count of the meat and fat materials used, and the presence of sufficient nitrite and elevated levels of salt. There is also less  $O_2$  available for the bacteria inside the salami; so the reduced  $E_H$  value is another hurdle against spoilage. Nitrite inhibits microbial growth more effectively at low, or reduced,  $E_H$  values, but the main advantage of reduced  $E_H$  values is that there is less  $O_2$  available for aerobic bacteria such as Enterobacteriaceae and therefore their growth is suppressed. At the same time, the preferred lactic acid flora, predominantly made up of members of the genus *Lactobacillus*, are at an advantage as they do not require  $O_2$  in order to grow. The presence of salt and  $NO_2$  in salami during the initial stage of fermentation favours the growth of specific facultative anaerobic Gram-positive bacteria. At the same time it inhibits the growth of fresh meat spoilage bacteria which are primarily aerobic. The number of desired bacteria such as *Lactobacillus* spp. are generally low in fresh meat and are therefore frequently added in the form of starter cultures.

After fermentation for around 36–48 h, large amounts of lactic acid are produced. The decline in pH value becomes the next dominant hurdle for ensuring the microbiological stability of the product once the other hurdles such as nitrite and  $E_H$  value are less effective. During the first 3–5 days of fermentation, the temperature is gradually reduced to around 18–20 °C and the level of moisture within the room is reduced to around 86–88%. The air speed is also slowed down to around 0.5 m/s. Within the 3–5 days, the  $A_w$  drops below 0.95 and the growth of *Salmonella* spp. as well as other members of the family Enterobacteriaceae is inhibited. The pH value drops below 5.5 in this period of time and this is another effective hurdle against growth of Enterobacteriaceae. However, *Staph. aureus* is not yet controlled as the production of toxin by *Staph. aureus* is only inhibited by an  $A_w$  at or below 0.89 or a pH value below 5.2. *Salmonella* spp. are frequently a problem especially in salami made from chicken as chicken more often contains *Salmonella* spp. than other types of meat. The drop in pH value brings about

a few essential changes inside the salami as regards colour, taste, aroma, sliceability and microbiological stability as follows.

- 1 *Impact on colour.* A decreasing pH value speeds up the development of curing colour as this process occurs at a faster rate closer to a pH value of 5.2–5.3, the optimal pH range for development of curing colour. More undissociated nitrous acid ( $\text{HNO}_2$ ) is present at these reduced pH levels and larger amounts of NO are produced as a result (see Chapter 7, Section 7.3). The curing colour created during the decline in pH value is stabilized once the pH value is at 5.2 and below as nitrosomyoglobin is denatured by acidification as the pH value drops below 5.2. A pH value below 5.5 greatly influences the level of activity of the enzyme nitrate reductase and no, or very little, nitrate will be reduced to nitrite below this pH. This can present a problem when salami is produced with nitrate and needs to be acidified quickly. Low levels of nitrite are produced when a pH value of 5.5 is reached quickly, simply because there is insufficient time for the reduction of nitrate to nitrite before enzyme activity from nitrate reductase comes to an end. The result is that the product will have a poor curing colour. Therefore, most salami today is produced with added nitrite, or a mix of predominantly nitrite and some nitrate and, in essentially all fast- and medium-fast-fermented products, nitrite is the material of choice. Large amounts of  $\text{O}_2$  are normally introduced into salami, especially during cutting and mixing. If this  $\text{O}_2$  is not removed during filling through the application of vacuum, the pH drops very rapidly, especially in small-diameter products (18–26 mm), increased levels of oxymyoglobin are denatured, rather than nitrosomyoglobin, and a pinkish colour will be the result.
- 2 *Impact on taste and aroma.* Acidification changes the flavour of the product and an acidic or tangy flavour is obtained. The strength of the sour taste depends on how low the pH value falls. At a pH of around 4.5–4.7 the taste is more acidic than at a pH of around 5.0. At pH values below 5.0, the conditions are favourable for heterofermentative (heterolactic) *Lactobacillus* spp. and they have a selective advantage over homofermentative (homolactic) *Lactobacillus* spp. Besides producing large quantities of lactic acid, which is desirable, heterofermentative *Lactobacillus* spp. also produce large amounts of acetic acid,  $\text{CO}_2$ ,  $\text{H}_2\text{O}_2$  and ethanol, which are not desirable. These unwanted metabolism by-products give the product a vinegar-like taste. The formation of  $\text{CO}_2$  also causes pores to appear, which can be seen in the finished product. In severe cases, the casing can even burst as a result of large amounts of  $\text{CO}_2$ . The enzyme catalase is not active at pH levels below 5.0 and  $\text{H}_2\text{O}_2$  produced is therefore not broken down into water and  $\text{O}_2$ . Increased levels of  $\text{H}_2\text{O}_2$  favour development of rancidity. They also have a negative effect on curing colour as  $\text{H}_2\text{O}_2$  is a strong oxidizing agent and can destroy the globin attached to myoglobin, resulting in a green–yellow colour in the finished product. A very fast decline in pH from its original

levels to below 5.2 also favours the growth and activity of heterofermentative *Lactobacillus* spp. A pH value below 5.0 brings the activity of proteases to a halt and so the proteases no longer produce compounds which contribute towards the typical salami flavour. Proteolytic enzymes break down proteins into peptides and free amino acids such as glutamic acid, alanine, leucine, valine and lysine, which contribute to the formation of the typical slightly cheesy flavour. The acid taste within salami is slightly reduced over prolonged periods of drying. Acids are oxidized over time and therefore have less of an impact on the taste on fermented salami dried for a long period of time.

- 3 *Impact on microbiological stability.* Lactic acid bacteria, which are mainly responsible for the formation of lactic acid and therefore for the decline in pH value, act in the water phase of the formulation. Any factor reducing the  $A_w$  below 0.95 at the beginning of fermentation, therefore, results in the formation of very little lactic acid or none at all. The curing colour will then be poor and, most importantly, the pH will never be an obstacle against microbial spoilage. It can be problematic to use freeze-dried meat in the recipe as this could lower the initial  $A_w$  quickly below 0.95, thus deactivating lactic acid bacteria. Ongoing acidification leads to a more microbiologically stable product as most bacteria are very sensitive to increased levels of acidity in their environment. Lactic acid obtained from fermented sugars as well as gluconic acid from GDL (as well as other acids produced in tiny amounts), are responsible for the decline in pH value. Enterobacteriaceae such as *Salmonella* spp. are inhibited at or below a pH of 5.5 and *Staph. aureus* does not produce toxin below a pH of 5.2. By reaching a pH value of 5.2 and below, the product is microbiologically stable owing to acidification. At reduced pH levels, nitrite also becomes a more effective obstacle against bacterial growth. The acid produced when starter cultures ferment sugar is more effective in inhibiting the growth of *Salmonella* spp. than the gluconic acid produced from GDL even when the final pH in the salami is the same. In small-diameter products, when the  $A_w$  in the outer layer of the sausage is reduced too quickly to below 0.95 and when the change in pH is due to starter cultures fermenting sugars, *Lactobacillus* spp. are inhibited at the beginning of fermentation. Therefore acidification never takes place and the product is at great risk of microbiological spoilage as the outer layers will have a high  $A_w$  for a long period of time. *Staph. aureus* can grow in those non-acidified areas of the product; it is only inhibited by an  $A_w$  at or below 0.89 and it takes time to reduce the  $A_w$  in the non-acidified areas below that level.
- 4 *Impact on sliceability.* Another important aspect of a decreasing pH value is that a move towards the IEP increases the possibility of removing moisture from the product as WHC is reduced at lower pH levels close to the IEP. As a result, large amounts of moisture can be removed from the salami during the decline in pH value from around 5.7 to 5.2. The

viscous sol, obtained during cutting in the bowl cutter or during mixing, is transformed into a solid gel at a pH of 5.2. At a pH value of 5.2, activated protein within the sol coagulates owing to acidification and the salami becomes sliceable. Subsequent drying increases sliceability even further. Crumbly products with poor slice coherency commonly result from the fact that insufficient levels of sol form during cutting or the fact that the temperature during mixing of the sausage mass is too cold with water present as ice. The latter means that little sol transforms into a gel via acidification. The time taken for the pH value drop below 5.2, or below 5.0, depends on the types of sugar added, the speed at which the starter cultures act and the temperature during the first 48 h of fermentation. A combination of fast-acting starter cultures, glucose (which is directly fermented into lactic acid) and elevated temperatures (around 26–28 °C) cause the pH value to drop quickly and pH values of or below 5.2 can be obtained within 24–36 h. The same is true when GDL is added as elevated temperatures speed up the formation of gluconic acid. However, a rapid decline in pH value (below 4.8 within 24 h) caused by GDL turning into gluconic acid quickly causes the formation of large amounts of CO<sub>2</sub>, which can lead to gassing in the packed salami. The final pH of the product depends on the amount of sugar or GDL added as greater amounts lead to higher levels of lactic or gluconic acid. However, the acidification that takes place owing to the action of starter cultures can be stopped once the desired temperature is reached by reducing the temperature within the fermentation room to around 12–14 °C as such temperatures are too low for lactic acid bacteria to ferment the remaining sugar into lactic acid. The residual sugar is then used for colour and flavour development rather than acidification. Acidification induced by GDL cannot be stopped, however, as it is a chemical process and, as long as free water and GDL are available, GDL turns into gluconic acid regardless of the temperature at which the reaction is taking place. After fermentation for around 36–76 h the salami has a pH of 5.2 or below. The pH value is the dominant hurdle against microbiological spoilage and the product is microbiologically stable. Generally, the pH drops further to levels between 4.6–4.9. A pH value of 4.6 is quite sour, which is usually not pleasing to the consumer. However, from a microbiological standpoint these low pH values are very safe. In countries such as the USA, a summer sausage is produced which has a pH in the range 4.6–4.8 or even lower, and this product is accepted by consumers.

#### *Smoking during fermentation*

It is very common to smoke raw fermented sausage to create the typical smoked colour and flavour. Smoking takes place at 20–25 °C. The application of smoke helps to prevent growth of moulds and a slight antioxidative effect is even seen on the surface as phenols, which are present in smoke, act as an antioxidant by deactivating free fatty-acid radicals. Products produced

worldwide have different colours from very light to dark black because of the different degrees of smoking. Most commonly a slight golden brown is desired. Salami is smoked for the very first time during fermentation once the red curing colour is fully developed and stabilized. Salami is not smoked within the first 36–48 h as components within smoke, such as phenols and other acids, have a negative impact on the development of curing colour, especially on the surface of the product. In fast- and medium-fast-fermented salami, smoke is generally applied after around 36–48 hours of fermentation. At this stage, the pH value has dropped to 5.2 or below and a stable curing colour has developed (at a pH value of 5.2 and below, nitrosomyoglobin has been denatured and therefore stabilized via the impact of acidification). The reduced level of humidity means that the casing is dry and therefore ready to be smoked. Smoke applied too early during fermentation results in a brown-coloured product. No mould is seen on the product after 36–48 h if the climate within the fermentation room is controlled properly. If the casing is too wet during the initial stages of fermentation and smoke is applied at this stage, a spotty, dark and uneven colour will be seen on the product.

Smoke is applied in intervals lasting 1–3 h several times per day for 2–3 days or as often as necessary until the desired smoke colour is reached. Cold smoking is not carried out as one long continuous process. Control of RH and air circulation is critical so that the casing is uniformly dried prior to smoking. During fermentation, as explained earlier, the RH in the chamber is slightly lower than the  $A_w$  within the salami. As a result, the casing generally has just the right level of moisture after fermentation for 36–48 h to take up smoke.

The small bundle of casing on the sausage after the clip can be used to check the RH in the room. This bundle should feel moist but not soaking wet or paper dry. If this bundle feels soaking wet, the RH is normally too high whereas, if the bundle feels paper dry and almost brittle, the RH is generally too low.

In large-scale production, all production steps such as fermentation, smoking and drying take place in one and the same room. A batch of salami remains in the same room until the desired loss in weight is obtained.

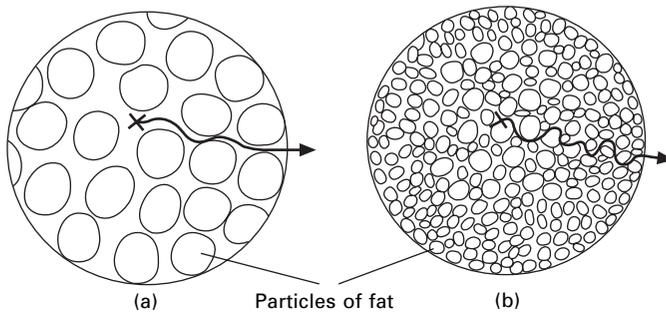
### *Drying of salami*

Based on the microbiological stability of the product at a pH of 5.2 or below, a fast-fermented salami is usually ready to be dried after around 36–48 h. A pH of 5.2 or below is reached in a medium-fast-fermented product after around 76–96 h. In drying the smoked product, the aim is to lose the desired amount of moisture in the shortest possible time without the occurrence of case hardening. The process of drying, and therefore the reduction in  $A_w$ , has a significant impact on taste, flavour, texture and colour of the product. It is hard to define the point at which fermentation ends and the process of drying starts because a loss in weight of the product occurs right from the beginning of the fermentation process. Generally, the drying phase starts once

microbiological stability is obtained (when the salami's pH value is stabilized), which is the case once the pH has reached 5.2. In a non-acidified salami, which is only slowly fermented and dried, drying basically starts right from the beginning of the fermentation process even though the time in which the pH declines from around 5.7 to 5.3 could be seen as the fermentation phase.

It would not be possible to dry salami if salt were not added to the product. As the RH in the drying room is constantly kept lower than the  $A_w$  of the salami, there is a difference in vapour pressure, which causes the removal of moisture from the outside layers of the salami. As a result, the concentration of salt is enhanced in the outside layers of the product owing to a decreased  $A_w$ . The difference between the moisture levels of the core and the surface of the product must be balanced out and therefore water diffuses from the core of the product towards the surface to equalize the levels of salt and  $A_w$ . The outer layers of the salami always have a lower level of moisture than the core of the salami because of the constant reduction in RH in the drying room and water continuously diffuses from the core towards the surface. Consequently, it can be said that salami dries from the inside out. The speed of evaporation of water from the surface of the product must be suitable for the speed of water penetrating from the core towards the surface. When moisture is removed more quickly from the surface of the product at a faster rate than that at which it diffuses from the core towards the surface, case hardening will be the result.

The sizes of the meat and fat particles present within the product, diameter of casing utilized, fat content of the product and air speed determine the maximum difference between the vapour pressures in the sausage ( $A_w$ ) and the atmosphere in the drying room (RH) and therefore the amount of moisture removed from the surface of the product within a certain period of time. Generally, parameters such as elevated temperatures, high air speed and low RH increase the removal of moisture from the surface of the product. Reduced temperatures, reduced air speed and elevated levels of RH slow down removal of moisture. These parameters have to be adjusted in order to dry the product as quickly as possible without the occurrence of case hardening. The amount of moisture to be removed from the surface of the product filled into a large-diameter casing is less than that to be removed from a small-diameter product as the distance from the core of the product to the surface is longer in a large-diameter product. Finely cut products with a particle size of 0.8–3.0 mm must be dried more slowly than products made from coarse meat and fat particles even when filled in the same-diameter casing. This is because the migrating moisture encounters meat and fat particles with a significantly larger surface area on its way from the core to the surface. Because of the presence of many small particles in the product, the stream of migrating moisture is redirected much more often than is the case in a coarse product, thus increasing the distance that moisture has to travel until it finally reaches the surface of the product. Figure 16.2(a) demonstrates the distance and the redirection that water faces on its way from the core to the surface



**Fig. 16.2** Distance and direction travelled by water from core to surface in (a) coarse and (b) finely cut products.

in coarse products and Fig. 16.2(b) the corresponding parameters for finely cut products.

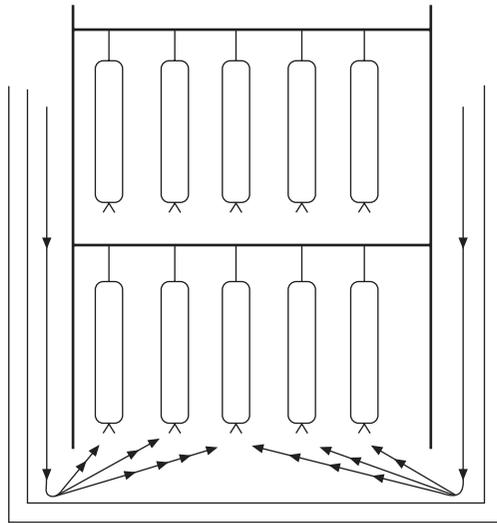
During drying, the temperature within the drying room is gradually reduced to 12–15 °C, the RH is gradually lowered to around 72–75% and the air speed is ultimately reduced to 0.1 m/s. Airflow must never come to a complete standstill as mould could develop quickly. Temperatures of around 12–15 °C are also used as they do not support the growth of mould. Through drying and the subsequent lack of free moisture, microbial growth as well as enzyme activity is largely inhibited. Enzymes such as proteases and lipases are still active during the drying process, however, and this is desired for flavour development inside the product. The speed of drying has to be adjusted to the diameter of the casing as well as to the particle size of meat and fat shown inside the product. As during fermentation, moisture can be removed in the later stage of drying at a faster rate from small-diameter products with coarse meat and fat particles than from large-diameter products made from small meat and fat particles. As a result, the fermentation and drying programme has to be fine tuned according to these parameters. If a small-diameter product is fermented and dried using a programme designed for large-diameter products, slow and uneconomical drying will be the result and the  $A_w$  will remain too high for an extended period of time during fermentation. A higher degree of acidification will take place as *Lactobacillus* spp. can ferment sugars for a longer period of time into lactic acid, and mould will have a chance to grow as well. A similar principle applies during drying. If a product is not dried at the required speed, the desired firmness (or loss in weight) will not be obtained so soon and every day of extended drying owing to insufficient removal of moisture is very costly. The risk that mould grows as a result of ineffective drying is greatly enhanced as well. To optimize drying in such a scenario, the RH can be reduced and air speed can be increased, but care must be taken that these adjustments do not cause case hardening.

On the other hand, if a fermentation and drying programme based on a small-diameter product is applied to a large-diameter product, case hardening will occur, and microbiologically unstable as well as visually unattractive

products are the result. More moisture is removed from the surface of the product than is the amount penetrating from the core of the product towards the surface. Therefore, the stream of moisture is interrupted and case hardening is the result. To avoid case hardening in such a scenario and to remove less moisture from the surface of the product within a given period of time, the air speed can be reduced, the level of RH can be increased, or a combination of both.

Drying rooms require uniform temperature, humidity and air speed. Generally, obtaining an even climate within the room and making sure that the RH and air speed are the same in all its corners is more difficult in larger drying rooms. The longer the distance that the air has to travel, the more difficult it becomes to maintain a uniform airflow and level of RH. A uniform climate is essential to achieve the fastest possible drying time without case hardening and the occurrence of mould growth. Quite commonly, some of the salami placed in a room exhibits case hardening while other products display growth of mould. These are signs of an uneven airflow and an uneven climate overall. During production on a small scale, it is possible to counteract those problems by shifting trolleys around the room to overcome those shortfalls. On a larger scale, this option of solving the problem of an uneven climate is not possible. When there is uneven airflow in the drying room (which is a common problem especially in large rooms), or products of different diameters or/and particle sizes are in the same drying room at the same time, the speed of drying is adjusted to the product most liable to case hardening (that from which the smallest amount of moisture can be removed within a given period of time before case hardening occurs; usually large-diameter products with small meat and fat particles). By doing this, the cases of all the other products, which could be dried more quickly, do not harden either but the drying of products in the room from which removal of moisture could take place at a faster rate (small diameter and/or coarse meat and fat particles) is less economical. Inefficient removal of moisture favours the growth of unwanted mould and therefore products of the same, or similar, diameter should be dried whenever possible at the same time in the same room.

During drying, if growth of mould is seen, it is generally more effective to reduce the RH in the room slightly and to slow down the air speed than to create conditions with elevated RH and high air speed. Elevated levels of RH favour growth of mould while high air speed favours case hardening at the same time. Depending on the air speed inside the drying room, the amounts of moisture removed from the surface of the product are vastly different. Fast-moving air removes significantly more moisture from the surface of the product than slow-moving air at a given RH. If freshly filled salami is placed in the same drying room together with products that have been dried or fermented for a few days already, the freshly filled product is hung in the upper area of the trolley and the products dried for a while already are placed near the bottom. Air travelling downwards along the walls

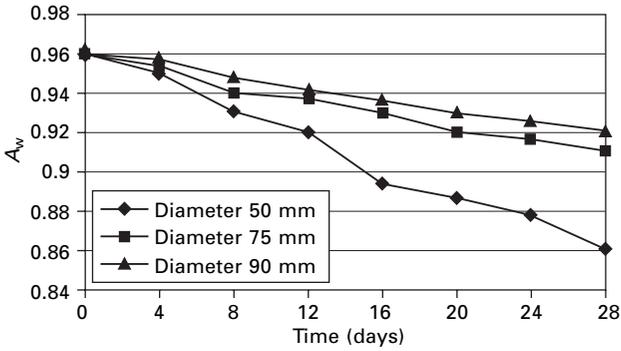


**Fig. 16.3** Positioning of salami in a drying room.

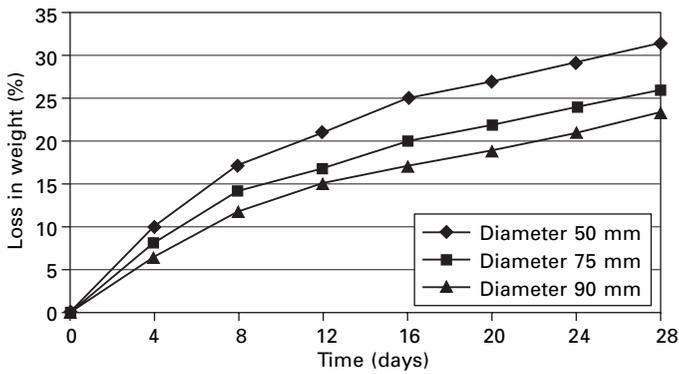
inside the drying room turns once it hits the floor and a slightly increased air speed is seen near the floor as a result. If fresh products were placed in these lower areas, the risk that case hardening occurs is increased. Figure 16.3 shows that fresh salami should be placed on the top layer whilst salami, fermented and dried for several days already, should be placed at the bottom owing to the higher air speed in the lower area.

Products filled into casings of different sizes and which are present in the same room for fermentation or drying commonly end up either with case hardening or mould on the outside. Case hardening in these cases occurs when moisture is removed too quickly from the surface of the large-diameter products but the level of moisture is too high for the small-diameter products, from which moisture could be removed even more quickly (Fig. 16.4). Generally, products with similar particle sizes filled into casings of a similar diameter should be fermented at the same time. Of course, filling up a fermentation room with the same type of product would be perfect but this is not possible in many cases.

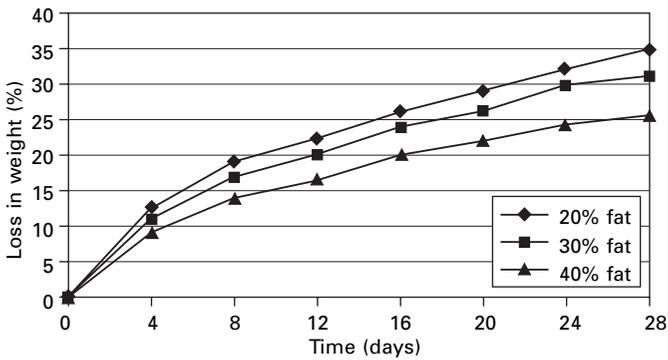
Even when the diameters of the casing utilized are the same, a significant difference between the particle sizes of meat and fat particles present results in vastly different drying behaviours (Fig. 16.6, Fig. 16.7 and Fig. 16.8). Significant differences in particle size cause significant differences in behaviour during fermentation and drying and products with different particle sizes cannot be treated properly in the same room. Moisture has to be removed very slowly from superfine salami owing to the high density of the sausage mass as well as the large surface area of all the small meat and fat particles. Slow removal of moisture from a coarse product, however, would most certainly cause growth of mould and, in this case, moisture could be removed



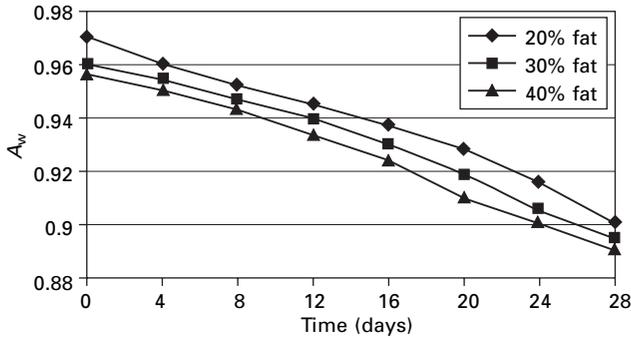
**Fig. 16.4** The effect of different product diameters on the reduction in  $A_w$  in salami over 28 days.



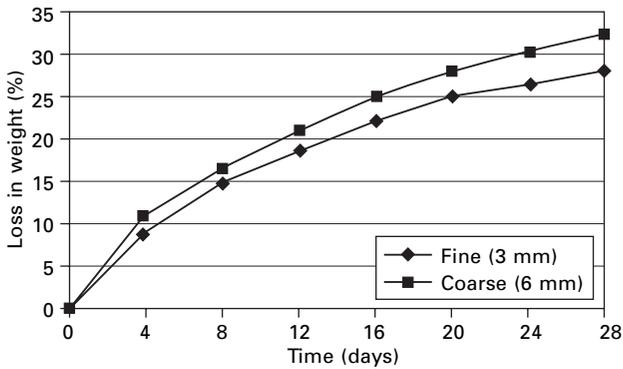
**Fig. 16.5** Loss in weight of salami filled into different diameters during drying over 28 days.



**Fig. 16.6** Different levels of weight loss in salami during drying over 28 days, based on the levels of fat in the product.



**Fig. 16.7** Reduction in  $A_w$  in salami during drying over 28 days, based on the levels of fat in the product.



**Fig. 16.8** The impact of different particle sizes of meat and fat on weight loss during drying over 28 days.

much more quickly from the surface of the product. Having a high  $A_w$  for a prolonged period of time within the coarse product means that *Lactobacillus* spp. have a long time in which to ferment sugars and a lower pH value can be the result. The loss in weight in the coarse product is also greatly slowed down and a much longer drying time is required to achieve the desired loss in weight. Products filled into larger-diameter casings generally have a lower final pH value than small-diameter products do, even though the same amounts of acidification materials such as GDL or sugar, in combination with starter cultures, are added. This is because the  $A_w$  remains higher for a longer period of time in the core of the product and the lactic acid bacteria are more active, producing elevated levels of lactic acid. However, lower pH values do not automatically result in a firmer product and it is not the case that slightly more acidified products have a firmer texture. During drying, salami filled into larger-diameter casings lose less weight in per cent within a given period of time than small-diameter products do (Fig. 16.5). This is especially the case in the initial stages of fermentation as the surface area of larger-diameter

products is smaller than that of smaller-diameter products. Small-diameter products demonstrate the largest surface area in relation to their weight.

Case hardening has to be avoided during fermentation and drying as it can lead to serious microbiological problems or other product shortcomings. It is not a problem from a microbial point of view if case hardening occurs in fast-fermented salami after the pH decreases below 5.2 within the first 36–48 h as a pH of 5.2 or below stabilizes the product. Case hardening slows down the process of drying afterwards, however. The desired firmness, or loss in weight, is in some cases never obtained or it can take considerably longer, which is costly. As the pH value is generally at levels of 4.6–4.8 within fast-fermented salami, and if case hardening occurs, heterofermentative *Lactobacillus* spp. will have sufficient moisture for a long time and large amounts of H<sub>2</sub>O<sub>2</sub> and CO<sub>2</sub> will be produced. The development of rancidity is therefore speeded up and an enhanced number of pores, or tiny holes, can be seen in the product. In severe cases, the product can even burst owing to the large amounts of CO<sub>2</sub> produced. Obtaining case hardening in a later stage in the production of fast-fermented salami is not a microbiological problem as all sugars have already been used up and the desired loss in weight has also been achieved. In fact, a slight degree of case hardening is occasionally produced purposely at the end of the drying process as sliceability of the product is improved as a result.

In medium–fast- and slow-fermented salami, if case hardening occurs in the early stages of fermentation and drying whilst the pH value, or  $A_w$  (in slow-fermented salami), the main hurdles against microbiological spoilage, have not yet been established, the situation is different. The  $A_w$  in the product is too high for too long and this leads to serious microbiological problems as bacteria such as *Salmonella* spp., *Proteus* spp., *Citrobacter* spp., *Enterobacter* spp., *Escherichia* spp., *Pseudomonas* spp., *Staph. aureus* and especially proteolytic enzymes can grow for a prolonged period of time before the product has acidified sufficiently. Proteolytic enzymes produce metabolic by-products which are extremely alkaline and unwanted bacteria, in combination with prolonged enzyme activity, can dominate the total microflora. Therefore, the desired lactic acid flora does not have a chance to produce sufficient lactic acid to stabilize the product from a microbiological point of view. In severe cases, the pH value never drops to desired levels and the product will be microbiologically spoiled, presenting a serious health risk. On the other hand, if drying takes place too slowly, slime frequently forms on the surface of the product. This spoilage on the outside is mainly caused by excess levels of moisture in combination with high temperatures. Some slime-producing bacteria are strongly proteolytic and the breakdown of protein leads to spoilage. Within the slime, bacteria such as *Staphylococcus* spp., *Micrococcus* spp. and yeasts are regularly present. If case hardening occurs in the later stage of drying when producing a medium–fast- and slow-fermented salami, this does not create a microbiological problem. The product is stabilized either by a pH value below 5.2 or by an  $A_w$  at or below 0.89. In summary,

case hardening is not a problem in medium–fast fermented salami as long as a pH below 5.2 is reacted beforehand. In slow-fermented salami, where the pH never drops below 5.5, case hardening is a microbiological problem if taking place before an  $A_w$  of 0.89 is reached, as no hurdle is in place against *Staphylococcus aureus*. Case hardening in a slow-fermented salami occurring before an  $A_w$  of 0.95 is reached is an even more serious problem as no hurdle is in place against *Enterobacteriaceae* either. Case hardening always slows down further drying, however. The presence of a dry ring on salami, as is obtained when the case hardens, however, is not attractive to the consumer.

It must be emphasized that smearing of fat during processes such as cutting, mincing, mixing and filling has to be avoided as the speed of drying is greatly reduced as a result. Once the speed of drying is reduced, the risk of obtaining case hardening is much greater. In summary, if case hardening occurs at the very beginning of fermentation stage, this can lead to microbiologically spoiled products especially in the manufacture of medium–fast- and slow-fermented salami. This is because the high  $A_w$  persists for a long period of time, which favours the growth of bacteria such as *Enterobacteriaceae* and the entire fermentation process can never take place.

Drying of salami in larger factories can operate on a system in which climatic conditions in one fermentation or drying room are utilized to regulate climate in another drying or fermentation room. Several drying and fermentation rooms with different climates are in operation at the same time and salami in varying stages of fermentation and drying fill up these rooms. The benefit of this system is that, when more moisture is required in one room, moisture can be drawn from another room with excess levels of moisture to the room requiring more moisture. The same applies to temperature and the exchangeable use of moisture and temperatures saves much energy (and therefore cost) as ‘creation’ of a climate is always connected with the utilization of large amounts of energy. Processes such as increasing or decreasing moisture levels as well as increasing or decreasing temperature in large fermentation and drying rooms is very expensive, and making use of the climate of other drying rooms reduces costs considerably. Of course, this system can only be used in companies which have quite a large number of fermentation and drying rooms.

#### *The microbiology of salami*

It is almost impossible to summarize all the microflora within salami completely as raw fermented salami is by nature a ‘living’ product and hundreds of millions of bacteria, from many different genera and species are involved (Fig. 16.9 and Fig. 16.10). Lactic acid bacteria are of utmost importance for acidification of salami. *Lactobacillus* spp. are the primary choice of bacteria utilized for acidification, which improves microbiological stability, colour, taste, texture and slice coherency of the product. Homofermentative spp. as *Lactobacillus* spp. are preferred to heterofermentative *Lactobacillus* spp. as

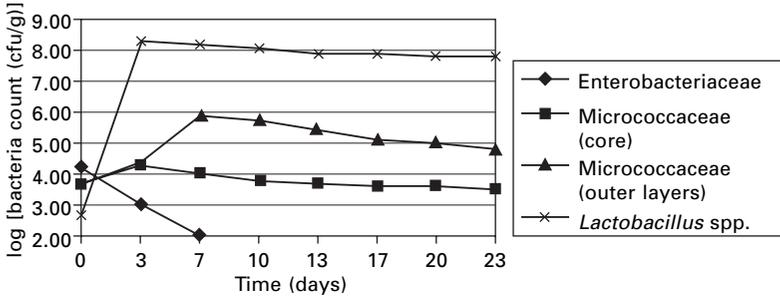


Fig. 16.9 Changes in microflora in fast-fermented salami.

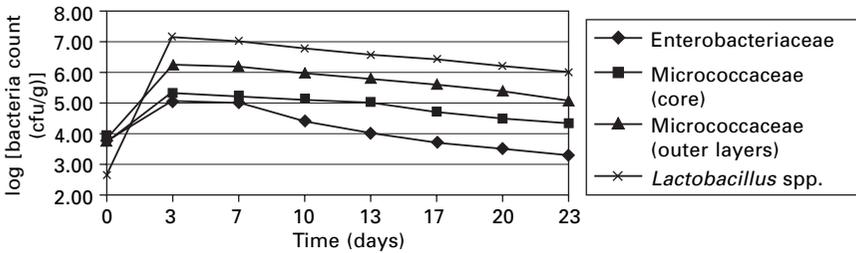


Fig. 16.10 Changes in microflora in slow-fermented salami.

heterofermentative *Lactobacillus* spp. produce, besides some lactic acid, acetic acid,  $H_2O_2$  and  $CO_2$ . Some *Lactobacillus* spp. are blamed for the production of biogenic amines through decarboxylation of the amino acids tyrosine and histidine.

*Pediococcus* spp., also a member of the lactic acid bacteria, support acidification as well, and both *Lactobacillus* spp. and *Pediococcus* spp. seem to inhibit production of aflatoxins. Normally, salami have a TPC of around  $10^6$  per gram of product at the point of filling and lactic acid bacteria grow to  $10^8$  per gram of product within the first 3–5 days of fermentation. Other lactic acid bacteria such as *Streptococcus* spp., *Enterococcus* spp. and *Leuconostoc* spp. are frequently present in salami at the beginning of fermentation. *Micrococcus* spp. and non-pathogenic species of *Staphylococcus* have a major positive impact on the development and stability of the curing colour as well as the flavour of salami. Most of those bacteria produce the enzyme catalase, which slows down rancidity as it breaks down  $H_2O_2$  into water and  $O_2$ . *Micrococcus* spp. in particular reduce nitrate very effectively to nitrite, thus helping formation of a strong curing colour. *Micrococcus* spp. and *Staphylococcus* spp. are found commonly on the surface of dried products as they require  $O_2$  for living. *Staph aureus* has to be tightly controlled by pH and/or  $A_w$  as it can cause serious microbiological problems. An  $A_w$  at or below 0.89 or a pH at or below 5.2 controls *Staph. aureus* and inhibits toxin production. Levels of *Staph. aureus* between  $10^3$  and  $10^4$  per gram of salami are acceptable but should be below that in the finished product.

*Salmonella* spp. are regularly present in meat and are controlled by an  $A_w$  below 0.95 or a pH value below 5.5. In fast- and medium-fast-fermented salami, an  $A_w$  below 0.95 is obtained within a few days of fermentation and therefore *Salmonella* spp. are inhibited at an early stage. *Salmonella* spp. present a greater risk in slow-fermented salami, as hurdles such as adjustment of the  $A_w$  and pH values are put in place at a later stage of fermentation. A salami ready for sale should exhibit less than  $10^4$  of Enterobacteriaceae (such as *Salmonella* spp.) per gram of salami. *Campylobacter* spp. are very sensitive to reduced  $A_w$  levels and are generally not a risk in salami. *Clostridium botulinum* is a risk in raw fermented sausage mainly in products such as summer sausage which is fermented at temperatures above 30 °C. When poorly cleaned natural casings are used for the production of salami, *Clostridium* spp. can cause problems as they grow underneath the casings within the product. *Leuconostoc* spp. can form viscous strings when sucrose (dextran) is present in combination with high fermentation temperatures (26–30 °C). *L. monocytogenes* is regularly present in meat as well as in salami but during fermentation and drying the number should not exceed  $10^2$  per gram of product. However, some countries have food standards in place which demand *L. monocytogenes* to be negative in 25 g. Generally, raw fermented salami does not support the growth of *L. monocytogenes*, enterohaemorrhagic *Escherichia coli* and *Salmonella* spp. and these bacteria are even reduced during fermentation as a result of acidification to pH values at or below 5.0.

Some moulds produce the enzyme cellulase. This enzyme, predominantly produced by *Mucor* spp., can break down cellulose in fibrous and other casings. In severe cases the enzyme literally ‘eats’ the casing. *Mucor* spp. can be prevented or inhibited by the application of a proper fermentation and drying climate (not too humid) and the application of smoke at the right time before any mould is seen on the product. Treatment of the salami with sorbate or natamycin also prevents growth of mould. Final drying at an RH below 75% reduces the risk of mould growth, as mould-inhibiting substances commonly seen on salami such as phenols and formaldehyde are volatile and lose their effectiveness over time.

Yeasts are present within the salami mass at the beginning of production in low numbers and can only grow on the outside layers of salami since they require  $O_2$  for growth. Proper control of the fermentation climate and the application of smoke eliminate unwanted yeast.

### *Flavour in salami*

The flavour within salami depends to a large extent on the time given to the product to develop the typical salami flavour. In order to obtain the typical slightly cheesy salami flavour, enzymes such as proteases and lipases need time to act. During flavour development, proteases such as calpain and cathepsins break down proteins into peptides as well as free amino acids. Bacterial proteolysis, however, has little impact on the typical salami flavour. Free amino acids such as valine, leucine, taurine and glutamine are produced

through proteolysis and they contribute to flavour. Lipases break down fat into free fatty acids, which also contribute strongly to flavour.

These enzyme-based reactions are the major source of flavour in slow-fermented salami. Over 250 different flavour compounds are now known to be present in slow-fermented salami but no single determining flavour has yet been found. Even rancidity is desired in slow-fermented salami to a small degree as it contributes to flavour. Compounds such as aldehydes and ketones contribute to the 'desired' rancid flavour.

The factor 'time' does not play a role in flavour development in fast-fermented salami as those products are commonly sold within 5–21 days of production, depending on the diameter of the casing used. The flavour of products dried for a short amount of time is predominantly determined by their internal acidity as well as the addition of spices. Their acidity comes from either lactic acid or GDL, or a combination of both, and it gives the product a sour and tangy flavour. In the production of fast-fermented salami, there is no time for any significant enzyme activity such as proteolysis or lipolysis to contribute to flavour development. In the manufacture of medium–fast-fermented salami there is a small amount of time available for flavour development as these products are sold around 3–5 weeks after production. The final flavour in these products is determined by a combination of internal acidification, the spices introduced and the product proteolysis and lipolysis to some degree.

Smoking (see Chapter 6, Section 6.4) inhibits the growth of mould as phenols and carbonyls are present, but it also has a major impact on the flavour of the product. The presence of selected moulds on the surface of the product also contributes to flavour as they break down protein and fat and penetrate into the sausage. Some lactic acid is metabolized by moulds, which causes a rise in pH during extended drying periods.

Rancidity is generally an unwanted flavour in salami. Some degree of rancidity, however, is desired in products dried for a long time. These products are primarily appreciated by salami lovers and commonly not by the everyday consumer. To delay rancidity, fat with a low level of unsaturated fatty acids should be processed as a raw material and this fat should not be rancid at all at the point of processing. Filling a product under vacuum also reduces the level of O<sub>2</sub> inside the sausage mass, thus slowing down the development of rancidity. In addition, nitrite added to the product slows down the development of rancidity as NO binds the iron present in the mass (unbound heavy-metal ions, such as iron, speed up oxidation, causing rancidity). The presence of catalase, predominantly produced by members of the family Micrococcaceae, breaks down H<sub>2</sub>O<sub>2</sub> into water and O<sub>2</sub>, delaying rancidity. The application of smoke, as well as antioxidants, can also slow down rancidity by deactivating free radicals.

#### *Salami manufacture without a fermentation room*

There are some special methods for a fast reduction in  $A_w$  in salami to be

used when proper fermentation rooms are not available. These techniques are occasionally practised in a small-scale operation and products filled into casings up to around 60 mm diameter are treated this way.

#### Alternating programme

After filling, the salami is kept in a low RH (60–70%) and fast air speed for around 10–16 h at 22–26 °C. It is kept to a point shortly before case hardening would occur. At this point, the RH is increased to around 92–94% for several hours. Afterwards, the RH is lowered again and a high air speed is applied again for around 8 h. This treatment reduces the  $A_w$  quickly below 0.95 and more gentle and gradual drying can follow. This method of reducing the  $A_w$  quickly is occasionally used in the manufacture of slow-fermented salami where the pH value never acts as a hurdle. Such a quick reduction in  $A_w$  during the initial stage of fermentation requires sound knowledge of the process and experience as, once case hardening occurs, drying afterwards would be greatly reduced overall. This treatment therefore has to be finely tuned and parameters such as the different diameters of the casings and the sizes of meat and fat particles will vary the conditions required.

#### Salt method

Filled salami, containing around 22 g of salt per kilogram of product, is placed in tubs or containers and covered in salt. The salami is then covered for around 3 days under chilled conditions. The salt, which is highly hygroscopic, is changed every day. Water penetrates out of the sausage into the salt as the concentration of salt is much higher within the surrounding salt itself than inside the sausage. This results in a fast reduction in  $A_w$  within the sausage. This method is sometimes used in the manufacture of slow-fermented salami. No, or very little, acidification takes place as lactic acid bacteria, such as *Lactobacillus* spp., do not have sufficient moisture at an  $A_w$  below 0.95 to ferment the sugars present in meat into lactic acid. The maximum diameter of products treated this way is around 60 mm as the reduction in  $A_w$  in larger-diameter products would require a significantly longer time.

#### Brine method

Filled salami is placed in brine containing 10–14% salt and the high concentration of salt within the brine lowers the  $A_w$  of the sausage fairly quickly. This method has the disadvantage that some myoglobin is washed out during soaking and less curing colour is seen in the final product.

#### Vacuum drying

The filled salami is placed in a vacuum of around 60%. A full vacuum cannot be applied as the clip on the casing would move or the casing would burst. After around 2–5 h the vacuum is released and another 3–6 h later, a slight vacuum is applied again. The vacuum applied opens up capillaries and moisture can be removed during the non-vacuum periods efficiently before the product is placed under a vacuum again.

All these alternative methods can only be used in small factories and do not suit large operations, their advantage being that most of those methods can be used without having to have a proper fermentation room as the  $A_w$  is quickly reduced below 0.95, inhibiting the growth of *Salmonella* spp. Further drying to a lower  $A_w$  also eventually stabilizes the product against *Staph. aureus*. Safe, secure and efficient fermentation as well as drying of salami without proper fermentation and drying rooms is hard to achieve. Not being able to control climatic conditions such as the RH, temperature and air speed leads either to the formation of case hardening if large amounts of moisture are removed from the surface of the product too quickly or to non-effective drying and the growth of unwanted mould if the RH is too high. Therefore, all medium- and large-scale operations have proper fermentation and drying rooms in place.

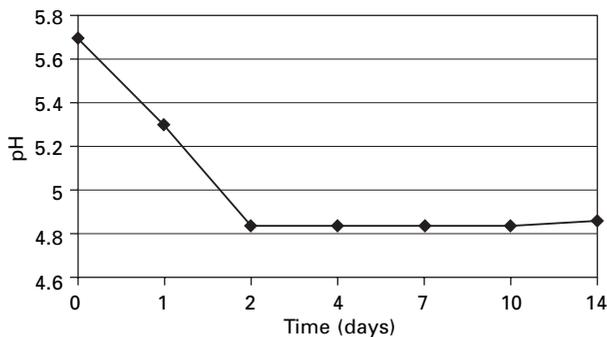
Salami, produced with GDL, can be made on a small scale without proper fermentation and drying rooms. The filled product is placed in an area with a temperature of between 22 and 26 °C for around 36–48 h. The sausage is showered every 3–4 h for several minutes only to maintain a moist surface to avoid case hardening and the salami should be exposed to moderate air speed. After 36–48 h, the pH value has dropped below 5.2, making the product microbiologically stable. The salami is cold smoked several times and then placed in an area with low air speed (around 0.1–0.3 m/s) for further drying. The utilization of GDL is recommended within this method as the conversion of GDL into gluconic acid is a chemical process, as opposed to a microbiological process such as applying starter cultures and sugars, and is a safe way of acidification. However, starter cultures can also be used but a chemical conversion of a material into acid is a more secure way than a biochemical method where living organisms have to ferment a substance to obtain the desired acidification. When working with GDL, at least 8 g should be applied per kilogram of sausage mass so that the pH value drops to a safe level of around 4.8. In extreme cases, the freshly filled product containing GDL or starter cultures and sugars is placed for 24 h in warm water (24–28 °C) which means that the product is in 100% conditions. The water is at the temperature required for starter-cultures to ferment sugars into lactic acid as well as for GDL to hydrolyse into gluconic acid. A small degree of myoglobin will be washed out during soaking but this is not of concern as the salami made in this way is not intended to be a 'top-quality' product. The intention is rather to make salami in a simple way. The product is removed from the water and hung at 24–28 °C under conditions of high humidity for one more day. If the level of humidity cannot be controlled, the product is showered every 2–3 h for a few minutes to maintain a high level of moisture on the surface of the product. The drop in pH value below 5.2 will be achieved after 36–48 h and the product is stable as a result. Smoking and some degree of drying complete the process.

In the final stages of drying a salami, the product is exposed to a temperature of around 12–14 °C, an RH of 70–75% and an air speed of around 0.1–0.2

m/s. The air speed must be greater than 0 m/s because mould would grow quickly if there was no airflow. Mould-inhibiting substances in salami such as phenols and formaldehyde are volatile and their impact against growth of mould is reduced over time. Treating the product with materials such as sorbate or natamycin helps to inhibit mould growth during the final stages of drying, but mould growth can also be inhibited simply by having the proper climatic conditions in place. Drying is continuous until the desired loss in weight, or  $A_w$ , is achieved. In products stabilized against microbiological growth by their  $A_w$  value, the  $A_w$  reached has to be 0.89 or below (*Staph. aureus* does not produce toxin at this level). In products stabilized by their pH value (5.2 and below) the  $A_w$  value is never important as a hurdle. It is important to dry the product to the desired  $A_w$  as flavour, firmness, colour and texture of the product are related to the  $A_w$ . On the other hand, excess drying is not beneficial in terms of the economics of production because less salami, based on weight, will be sold to the customer. The colour of a dried salami is influenced by the loss of weight as the material that predominantly loses moisture during drying is muscle meat (and not fat). This causes nitrosomyochromogen within meat particles to be concentrated, resulting in a darker colour.

#### *Fast-fermented salami*

A large amount of salami today is produced quickly and used as pizza topping or for other purposes. Fast-fermented salamis are stabilized by pH value only and water activity never comes into play as a hurdle against microbiological spoilage. Generally, these products are sold within 5–10 days of manufacture and small–medium-sized diameter casings are utilized. For the purposes of acidification, fast-acting starter cultures in combination with glucose and/or GDL are the materials of choice. Some products are made with GDL only. The pH value of fast-fermented salami is around 4.6–4.8 in the finished product, which makes it microbiologically stable (Fig. 16.11). Commonly, the addition of around 10 g of glucose, or a combination of 5 g of glucose (and starter cultures) and 5 g of GDL per kilogram of



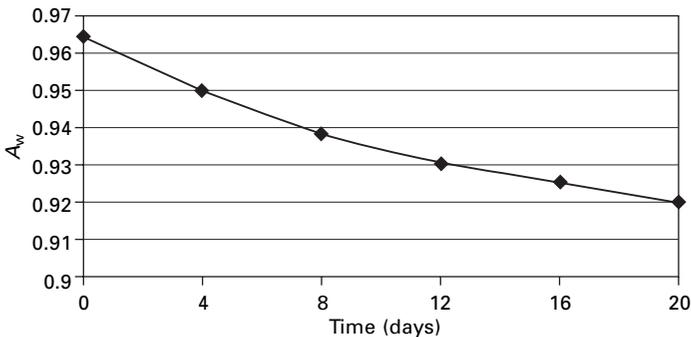
**Fig. 16.11** Decrease in pH in fast-fermented salami.

salami reduces the pH value by one full pH unit (from 5.7 to 4.7, as an example). Alternatively around 10 g of GDL are added per kilogram of sausage mass which also reduces the pH value by around one pH unit. Nitrite (and no nitrate) is added as there is not sufficient time for nitrate to be reduced to nitrite. Nitrite also has to act as a hurdle against microbiological spoilage during the initial stage of fermentation. Starter cultures commonly used in the manufacture of fast-fermented salami contain predominantly *Lactobacillus* spp. and *Pediococcus* spp. but occasionally also small amounts of *Micrococcus* spp. and *Staphylococcus* spp. for their contribution to colour and flavour within the product. Flavour in fast-fermented salami is greatly determined by the presence of lactic acid and the low pH value gives a sour and tangy flavour. Very little of the typical salami flavour is present as there is insufficient time for enzymes to break down proteins and fat. As a result, the spices added to the product in combination with its acidic and tangy note determine the flavour. Fermentation usually takes place at temperatures between 26 and 30 °C as this enables fermentation to proceed quickly. The final  $A_w$  of the product is around 0.92–0.94 (Fig. 16.12), which represents a loss in weight of between 10% and 20%. Large volumes of fast-fermented salami are produced in a 5–6 day cycle and salami produced on Monday is sold (or packed) on Friday or Saturday of the same week. The food standards of some countries insist that the pH value within fast-fermented raw fermented salami must drop below 5.2 within 48 h.

Table 16.1 shows a typical fermentation programme for fast-fermented salami filled into 45 mm fibrous casings

#### *Medium-fast-fermented salami*

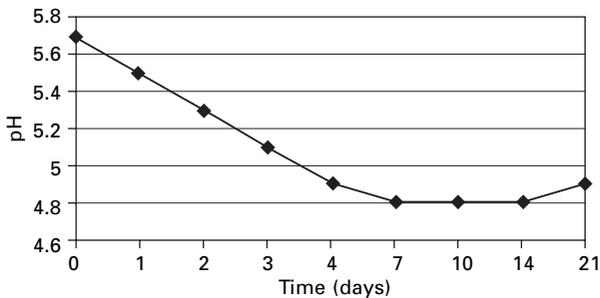
Medium-fast-fermented salami is usually acidified by a mixture of glucose and GDL, or by the addition of sugars together only with starter cultures. If sugars are used, the majority of the sugar added is glucose as this causes the pH value to decrease quite rapidly below 5.2 (Fig. 16.13) but other sugars such as lactose are added as well. Combinations of glucose, lactose, maltose



**Fig. 16.12** Decrease in  $A_w$  in fast-fermented salami filled into 60 mm casings over 20 days.

**Table 16.1** Typical fermentation programme for fast-fermented salami in a 45 mm fibrous casing

Time	Temperature (°C)	RH (%)	Smoke
1–6 h	24–26	50–60	No
Day 1	24–26	90–92	No
Day 2	20	90–92	No
Day 3	20	88–90	Yes
Day 4	18	85–87	Yes
Day 5	18	83–85	No
Day 6	16	80–82	Yes
Day 7 onwards	14	72–75	No

**Fig. 16.13** Decrease in pH in medium-fast-fermented salami.

and some GDL can also be added. The starter cultures chosen do not work as quickly as the starter cultures applied to fast-fermented salami and the pH reaches 5.2 after around 3–5 days. Temperatures of 22–24 °C are normally applied during the initial stage of fermentation. The addition of 4 g of glucose and around 6 g of lactose normally lowers the pH to around 5.1. Medium-fast-fermented salami, depending on the diameter of casing used and desired weight loss, are generally sold 14–28 days after production. Nitrite (and no nitrate) is added and nitrite becomes the first hurdle against microbiological spoilage. A decreasing pH value is the next hurdle and levels of 4.8–5.0 are commonly aimed for. When the pH value remains below 5.2,  $A_w$  is established as the next hurdle. Some medium-fast-fermented salami when sold are stabilized against microbiological growth only by their pH value below 5.2, some are stabilized by an  $A_w$  below 0.89 and others are sold with a pH value of around 5.0–5.1 and an  $A_w$  of around 0.93. At these pH levels, growth of *Staph. aureus* and *Salmonella* spp. is inhibited. An  $A_w$  of 0.93 is an additional hurdle against *Salmonella* spp. as an  $A_w$  above 0.95 is required for *Salmonella* spp. to grow. Care has to be taken in medium-fast-fermented salami that the pH value does not rise above 5.2 as long as the  $A_w$  is not at or below 0.89 as no hurdle would be in place against *Staph. aureus* and this would be a serious health risk. An  $A_w$  of 0.89 or below is required for *Staph. aureus* not to produce its toxin. The flavour of medium-fast-fermented salami is due to

acidification, addition of spices and also some degree of proteolysis and lipolysis, if the product is dried for around 4 weeks. Generally, medium–fast-fermented salamis have a stronger salami flavour than fast-fermented salami.

### *Slow-fermented salami*

Slow-fermented salami is the ‘classical’ type of salami but it cannot be produced in many countries as their food standards call for a drop in pH value in a salami within the first 48 h of fermentation to 5.2 or below. ‘Classical’ salami never experiences this drop in pH value and  $A_w$  is instead the main obstacle in this product against microbial growth; the pH value never becomes one of the main hurdles. To produce a safe slow-fermented salami, as with all other types of fermented salami, the meat and fat raw materials must have a low bacteria count.

Small amounts of sugar are sometimes added to support the natural acidification achieved by the *Lactobacillus* spp. present in meat. Starter cultures, or more specifically protective (or competitive) cultures, are also frequently added to inhibit growth of bacteria that are naturally present but undesirable (such as *Salmonella* spp.) until an  $A_w$  of 0.95 is reached. Protective cultures, however, are not added for the purpose of acidification as such. Protective cultures frequently contain *Micrococcus* spp. and *Staphylococcus* spp. These bacteria are generally added for their contribution to development of a strong curing colour and excellent flavour, rather than for the purpose of acidification. Naturally present *Lactobacillus* spp. ferment added sugars, generally between 2 and 4 g per kilogram of sausage mass. If the pH value tends to drop to levels below 5.3–5.2, the temperature inside the fermentation room is reduced to 12–14 °C as the lactic acid bacteria stop fermenting sugars into lactic acid at such low temperatures. The remaining sugar is then utilized for the development of colour and flavour.

As a result of natural acidification, the pH value obtained is around 5.3–5.4, which is another hurdle against bacteria such as *Salmonella* spp.. It is not uncommon, however, for the pH value within the product to increase during the first 1–2 days of fermentation by around 0.1–0.2 pH units owing to enzyme activity until natural acidification starts to take place. Fermentation in naturally fermented salami is caused by the lactic acid bacteria naturally present in meat. The numbers of these bacteria can increase to  $10^5$ – $10^6$  per gram of product within 3–5 days of fermentation whilst other bacteria such as *Pseudomonas* spp. decrease sharply in numbers. Experience shows that the natural acidification is initiated first by some members of the family Enterobacteriaceae, followed by *Enterococcus* spp., *Pediococcus* spp., *Streptococcus* spp. and finally *Lactobacillus* spp. *Streptococcus* spp. ferment glucose into lactic acid at temperatures above 14 °C.

The pH value remains at around 5.3–5.4 until the  $A_w$  is at a suitable level to be a hurdle against microbiological spoilage. The pH value should not drop quickly below 5.5 as nitrate-reducing bacteria, such as *Micrococcus*

spp., do not reduce nitrate to nitrite at pH levels below 5.5, which is a problem when nitrate is present. A fair amount of nitrite is always oxidized to nitrate in any case, and this has to be reduced to nitrite again. If the pH value drops quickly, and nitrate is present, poor curing colour is the result as little nitrite would be present.

During initial drying, the  $A_w$  commonly drops below 0.95 after around 4–6 days, which provides sufficient time for natural acidification due to the action of *Lactobacillus* spp. and curing colour can develop as well. Natural acidification supports the formation of nitrous acid ( $\text{HNO}_2$ ) and elevated levels of undissociated  $\text{HNO}_2$  result in higher levels of NO, which forms the stable curing colour (see Chapter 7, Section 7.3). Drying of slow-fermented salami must not happen too quickly within the initial stage of fermentation as a reduction in  $A_w$  below 0.95 in the outer layers of the product would not provide sufficient water for *Lactobacillus* spp. to act. Poor curing colour would be seen in the finished product as there would be little undissociated  $\text{HNO}_2$ .

During this initial stage of fermentation, the low bacteria count of the meat and fat utilized, the addition of salt (at least 25 g per kilogram of product), nitrite and often some nitrate, and fermenting temperatures of only around 16–20 °C are the main hurdles against microbiological spoilage until an  $A_w$  below 0.95 is achieved. At an  $A_w$  below 0.95 growth of Enterobacteriaceae such as *Salmonella* spp. is inhibited and the loss in weight is around 15% at this stage. The loss in weight results in an increased level of salt at the same time in the product.

If the product is smoked, smoking takes place after around 48 h to prevent growth of unwanted mould. A large percentage of slow-fermented salami have surface mould on their surface. If this is the case, the salami is normally not smoked at all or is smoked slightly before the surface mould is applied. Application of mould happens via spraying after around 2–3 days. In the manufacture of non-smoked slow-fermented salami, mould is also frequently applied by dipping the freshly filled salami into a suitable solution.

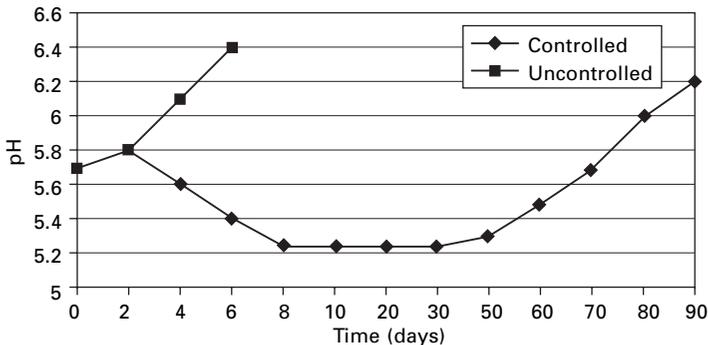
Slow-fermented salami is sold after 6 weeks to 5 months and the time of sale depends greatly on the diameter of the casing used. Some large-diameter products are even dried for 8 months to a year. The sol obtained during mixing of the salami mass transforms into a gel in slow-fermented salami owing to the presence of a low  $A_w$  in conjunction with high levels of salt. This gel is never fully acidified. This is in contrast with fast- or medium-fast-fermented salami, in which the transformation of sol into gel is achieved via the impact of acidification (pH value below 5.2). The final  $A_w$  in the product is normally between 0.82 and 0.88 and pH values of 6.0–6.2 are frequently seen, which do not present a problem in terms of microbial growth as an  $A_w$  below 0.89 stabilizes the product. Commonly, a mix of nitrite and nitrate is applied for the development of the curing colour and the application of nitrate ensures a stable colour even after drying for some months. To produce a salami by this method safely requires much experience and knowledge of the materials and processes used.

As this product is never fully acidified, the flavour of the non-acidified product is very distinctive; it is the slightly cheesy mouldy flavour typically associated with salami. The typical salami flavour is predominantly due to proteolysis (free amino acids) as well as lipolysis. Enzymatic alkaline metabolic by-products lead to an increase in pH value to levels above 6.0 in the finished product and therefore a slight degree of rancidity is frequently part of the flavour as well. The lipolytic activity of lipase from lactic acid bacteria is significantly less than that of *Micrococcus* spp. and lipase from moulds is also of importance in slow-fermented salami. After lipolysis, fewer triglycerides are present and more diglycerides and free fatty acids are obtained. The flavour in salami dried for a long period of time can be due to up to 300 different compounds. The flavour is typically a result of acidity, proteolysis and lipolysis and the presence of aldehydes and ketones and many other compounds.

Caseinate is regularly added to slow-fermented salami at 5–10 g per kilogram of product. Caseinate binds water to some degree and drying is slightly slowed down as a result of its presence. A prolonged period of drying gives enzymes the opportunity to create higher levels of free amino acids and free fatty acids, which contribute to flavour. The flavour from caseinate itself naturally matches the flavour of salami dried for a long period of time. A degree of bitterness can be seen in non-acidified salami dried for a long period of time as a result of the death of proteolytic enzymes.

Case hardening has to be avoided during the early stage of fermentation and drying, as a high water activity supports the activity of proteases. Large amounts of highly alkaline by-products are formed by proteases, causing a rapid raise in pH value. This results in uncontrolled fermentation as the natural lactic acid flora never has a chance to acidify the product to levels around 5.3. If the salami has a high pH value for a prolonged period of time, there is no hurdle in place against *Salmonella* spp. and *Staph. aureus*. Both can therefore grow in an uncontrolled manner and the product is unsafe.

Figure 16.14 shows the pH values of controlled fermentation (full diamonds) and uncontrolled fermentation (full squares) in slow-fermented salami. Even



**Fig. 16.14** Changes in pH during controlled and non-controlled fermentation of slow-fermented salami over 90 days.

though the final pH values reached are similar, the difference is that in a controlled fermentation a low  $A_w$  stabilizes the product whilst obtaining a high pH value as a result of prolonged drying. In an uncontrolled fermentation, the pH value keeps rising right from the beginning without ever decreasing leading to immediate spoilage.

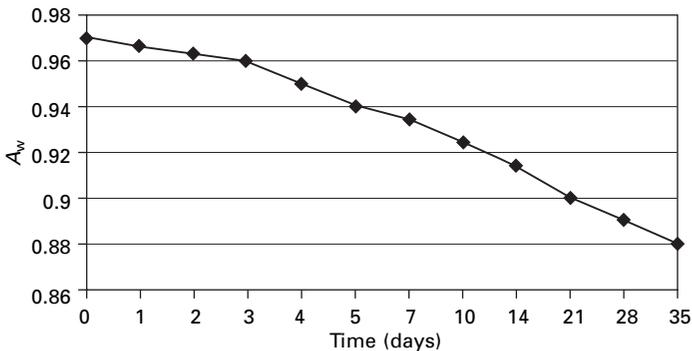
If case hardening occurs in the late (or later) stages of drying when the product is microbiologically safe and at an  $A_w$  below 0.89, this is generally not a problem. The only difficulty is that case hardening is not appealing to the customer. There is greater risk of case hardening in large-diameter slow-fermented salami, just as in the manufacture of fast- and medium-fast-fermented salami. Less water can be removed from the surface of the product within a certain period of time as water has to travel a longer distance from core to the surface. The extended distance slows down the speed at which water travels. This explains why drying has to take place at a slower rate in large-diameter products than in small diameter-products. Figure 16.15 shows the decrease in  $A_w$  in slow-fermented salami.

Figure 16.16 illustrates the sequence of hurdles in slow-fermented salami where finally an  $A_w$  below 0.89 stabilizes the product. One hurdle is constantly in place right from the beginning of the process.

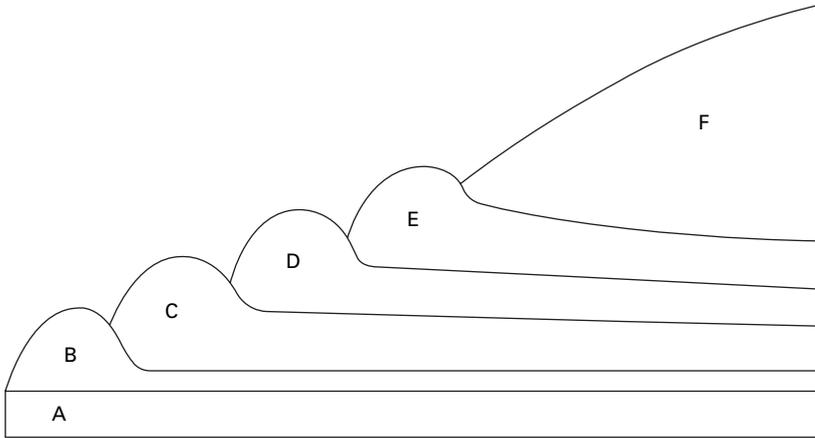
As in the manufacture of other types of salami, smearing of fat must be avoided at any stage of the process. Fat smearing would cause capillaries to be closed and therefore it would not be possible to use  $A_w$  as a hurdle since drying, and therefore the removal of moisture, would be badly affected. As the pH value never becomes an effective hurdle against microbial growth in slow-fermented salami, it is detrimental if case hardening occurs as a result of smearing. This could give unwanted bacteria an advantage over the desired microflora and microbiological spoilage could be the result.

#### *Salami with a surface mould*

In places such as France and Italy, a large percentage of all salami produced has mould on its surface. The presence of this mould is intentional and it is applied to the surface of the product in either a dipping or a spraying process.



**Fig. 16.15** Decrease in  $A_w$  in slow-fermented salami.



**Fig. 16.16** The sequence of hurdles in the production of slow-fermented salami.

A, meat and fat material showing a low bacteria count; B, presence of nitrite; C, reduction in the  $E_h$  value; D, competitive flora (lactic acid bacteria); E, decrease in the pH value; F, reduction in the  $A_w$  value as a result of drying, therefore strengthening (increasing) the  $A_w$  value as a hurdle.

Genera of *Penicillium* are generally chosen. Few salamis have yeasts such as *D. hansenii* or *C. famata* on the surface. Yeasts are sometimes introduced directly into the sausage mass for flavouring purposes and *D. hansenii* at levels of  $10^6$ – $10^7$  per gram of sausage is generally chosen. Mould is applied either to medium- or slow-fermented products; these products are generally fermented and dried for at least for 4–6 weeks. The colour of mould present on the surface of the product should be white or off-white, rather than green, yellow, blue or black. All unwanted moulds are usually of one or more of these non-white colours.

The desired mould should cover the product surface evenly and fully. If growth of mould is not taking place at the desired speed, a slight rise in temperature as well as an increase in RH often provides the small change in climate required for optimal growth. A mould-dipping solution contains around  $10^6$ – $10^7$  cells per millilitre of water. When the solution is applied by spraying it on to the surface of the product, rather than by dipping the filled product into the solution, it should not be too cold. The surface of the casing should also not be too moist (wet) as the mould spores cannot grip on to wet surfaces. Generally, mould solution is sprayed on after fermentation for around 2 days once all condensation water is removed and drying has already taken place to some degree. Slightly smoked sausages can only be inoculated, typically via spraying, once volatile smoke components such as phenols and formaldehyde are no longer present on the surface of the product, as they would interfere badly with the growth of mould. More specifically, around 24–48 h should pass between a light application of smoke and the subsequent spraying of the product. The majority of mould-covered salami are never

smoked, but a touch of cold smoke at around 20–25 °C after fermentation for around 2 days helps to suppress any unwanted mould.

The presence of mould on the surface of the product stops, or delays, case hardening and contributes positively to the flavour of the product as mould generally contains proteases and lipases. Mould also protects the product, or the surface of the product, from the impact of light and O<sub>2</sub> and therefore stabilizes the colour and delays rancidity. Before the product is packed and sold, most of the mould present on the surface is brushed off as some mould can grow to a substantial length. If an uneven layer of mould is obtained during drying, the brushed salami can be rolled in talcum or flour so that it looks as if the mould covers the surface of the product more evenly.

#### **16.3.4 Slicing**

The majority of small-diameter raw fermented products are not sliced and sold by piece instead. Products fermented in natural casings, and even large-diameter products, are commonly not sliced and pre-packed but sold to delicatessen shops or lunch bars where slicing takes place. Salami filled into medium- and large-diameter fibrous casings are very often sliced and easy-to-peel casings (see Chapter 35, Section 35.5) are used. Slicing takes place on high-speed slicing machines and a high degree of firmness, obtained through drying, supports sliceability. Commonly, the salami exhibits a slight degree of case hardening at the end of the drying period which aids sliceability. Large-diameter products are stored at around 0 °C for several hours prior to slicing to increase the firmness of the product and sliceability at the same time. Formation of condensation water should be avoided during slicing especially when dealing with products stabilized by an  $A_w$  below 0.89. If condensation water is present, then there is essentially 100% moisture on the surface of the salami and therefore there is sufficient free water for bacteria to grow in the outer layers. When condensation water forms during slicing of  $A_w$ -stabilized products, these products afterwards have to be stored chilled at a temperature below 4 °C to avoid bacteria growth. Condensation water is not such a large risk in products stabilized at a pH value below 5.2 as  $A_w$  has never been established as the main hurdle. The formation of condensation water is of no advantage, however, either.

#### **16.3.5 Packaging and storage**

When sold in portions (rather than sliced), most salami products, which have stabilized by either the  $A_w$  or pH value, are commonly vacuum packed or packed under a modified atmosphere. Some products sold in portions are occasionally packaged simply in nettings or in foil showing tiny holes, but further drying takes place when salami is packaged like this, which in most cases is not desirable. If these types of permeable packaging are used, they are applied to products which are stabilized by an  $A_w$  below 0.89 as slow

further drying reduces the  $A_w$  even further, thus strengthening this hurdle. Sliced salami products, whether they are pH or  $A_w$  stabilized, are also vacuum or modified atmosphere packed. When vacuum packed, the individual salami slices tend to stick together and cannot be separated easily and therefore the individual slices end up badly deformed. Products of any diameter, small or large, which are stabilized via the impact of a low pH value (below 5.2) are predominantly packed under vacuum as this type of salami has lost between only 15% and 20% in weight and no further loss in weight is desired. These products are commonly manufactured via fast and occasionally medium-fast fermentation and are generally products sold at a low price; excess drying is therefore not wanted. Salami packed under vacuum does not lose any additional weight after being packed and non-sliced, or portioned, products are generally sold on the basis of a defined weight. Once the desired weight of the portioned products has been obtained during drying, vacuum packing takes place straight away. Any additional loss in weight is an economic loss rather than a benefit in any way as the product is already stabilized by its low pH value against microbiological spoilage.

The packing materials used should have high oxygen and moisture barrier characteristics to avoid exchange in moisture between product and atmosphere. The permeability of packaging materials towards  $O_2$  should be less than  $10 \text{ cm}^3/\text{m}^2 \text{ day}$ . Vacuum packing products inhibits growth of mould as mould requires  $O_2$  for growth. Products which have been vacuum packed occasionally exhibit growth of mould once the packing is opened as internal moisture has been drawn towards the surface of the product during packaging and then the enhanced levels of moisture, especially on the surface, give mould an opportunity to grow.

In the modified-atmosphere packing of salami, a mix of  $N_2$  as well as  $CO_2$  is used. The level of  $CO_2$  within the gas mixture is around 20–30% whilst  $N_2$  accounts for around 70–80%.  $CO_2$  acts as a preservative in the form of carbonic acid and enhanced levels of  $CO_2$  increase the acidity of the finished product.  $O_2$  should be present within a modified-atmosphere pack at levels as low as possible; a level up to 0.6% is the maximum. A level of  $O_2$  below 0.6% is beneficial to product shelf life. Sliced salami packaged in a modified atmosphere lies loosely in the packaging and therefore it is not deformed by the packaging. Hence, individual slices do not stick together as in the case of sliced products packed under vacuum.

Salami which is stabilized via a low  $A_w$  value (below 0.89) is commonly sold as a whole piece regardless of its size and diameter. It can also be sold in a sliced form, however. These products have lost around 30% in weight, are medium- to high-quality products and have been fermented either slowly or at a medium-fast rate. A large proportion of salami produced via medium-fast fermentation (during which acidification to a pH value of around 5.0 will have occurred) are subsequently dried until around 30% in weight is lost, thus reducing the  $A_w$  below 0.89. The combination of a pH value below 5.2 and an  $A_w$  below 0.89 makes these products double safe. When the

formation of condensation water has been avoided during slicing, products with a pH value of around 4.8–5.0, or an  $A_w$  below 0.89, are shelf stable without refrigeration. However, condensation water frequently forms during slicing and therefore most sliced products are stored and sold chilled at a temperature below 4 °C. Products which are stabilized by a pH value below 5.2, vacuum packed and sold as a whole piece or cut only into halves are commonly stored under refrigeration at a temperature below 4 °C in case condensation water was formed during packing. Storage at such temperatures does not allow *Salmonella* spp. or *Staph. aureus* to grow and is another effective hurdle besides the pH value.

A very critical point to remember is that the pH value of salami increases again during storage. If salami is stabilized by a pH value between 4.9 and 5.0, the pH increases over time as a result of proteolytic activity as highly alkaline metabolic by-products are produced. Once the pH value rises beyond 5.2, the low pH value, which is the main hurdle against microbial growth, is lost and the product becomes microbiologically unsafe if the  $A_w$  has not dropped to a level of, or below, 0.89 at this point. Generally, maintaining a pH value below 5.2 is not a problem in fast- or medium-fast-fermented products. This is because a very low, and therefore safe, pH value of around 4.6–4.8 is usually seen in the finished product, and the pH remains well below 5.2 even during a prolonged period of storage. These products are also commonly consumed well before shelf life expires. Problems might occur in salami, in which the drop in pH value reached levels of only around 5.0 as the pH value could rise beyond 5.2 within a relatively short period of time. At a pH value above 5.2, when an  $A_w$  below 0.89 has not yet been established, *Staph. aureus* is a serious microbiological risk as it will produce toxin. As a safeguard, salami stabilized via pH value must have a pH value below 5.2 at the end of the recommended shelf life or at point of consumption and not at point of sale, bearing in mind that salami, sold from the manufacturer to the customer (supermarket), may remain on the shelves for weeks before being finally consumed. Salamis stabilized via pH value are sold with a pH value around 4.6–4.8. This is still well below the critical point required for microbiological safety even if a slight increase in pH value occurs before the product is finally consumed.

Small white crystals are occasionally seen on the surface of salami and these crystals are made from creatine monohydrate. Crystal formation is found on the surface of products dried for a long period of time and creatine from meat itself is the source. The formation of white crystals occurs commonly on the surface of packaged products which are stored chilled, but crystals also form if the packed product is exposed to variations in storage temperature such as being stored in the chiller, placed for a while at ambient temperatures and then being placed again in the chiller. Creatine is very unstable in water and slight differences in moisture levels, intracellular or extracellular, cause creatine to be present in either its dissolved or its mineralized state. Mineralized creatine causes the white visible spots. 1 g of creatine monohydrate requires

78 g of water to dissolve, i.e. it has low solubility. These crystals are harmless for consumers but are not attractive and most consumers will not buy a product showing these crystals. So far, a full explanation of how to prevent the formation of these crystals, other than by avoiding variations in storage temperature, has not been produced.

## 16.4 Summary of critical production issues

- 1 Meat and fat materials should be processed and show a low bacteria count of  $10^2$ – $10^4$  per gram and a pH value of meat below 5.8 is optimal.
- 2 No antibiotics should be present within meat and no hard MDM should be used.
- 3 Fat must not be rancid and hard fat containing fewer unsaturated fatty acids is preferred.
- 4 Predrying of meat and fat reduces initial  $A_w$ .
- 5 The level of added salt should be at least 25 g per kilogram of sausage mass.
- 6 Nitrite and/or nitrate should be added at the highest permitted level.
- 7 Proper starter cultures in combination with sugars, or other acidifying material, should be added depending on the required speed of fermentation.
- 8 Smearing of fat should be avoided during mincing, cutting and mixing processes.
- 9 The optimal temperature of the finished mass prior to filling is between  $-4$  and  $0$  °C.
- 10 Smearing should be avoided during filling.
- 11 Conditions during fermentation and drying vary as follows: RH, between 93% and 72%; temperature, 26–12 °C; air speed, 0.8–0.1 m/s. The RH, temperature and air speed should gradually decrease during fermentation and drying.
- 12 Cold smoke should be applied for the first time after 36–48 h once curing colour is fully developed.
- 13 Drying of small-diameter products containing coarse meat and fat particles can take place at a faster rate than the drying of products filled into large-diameter casings containing finely cut meat and fat particles.
- 14 Salami is microbiologically shelf stable without refrigeration at a pH value below 5.2 or an  $A_w$  of or below 0.89.

# 17

## Typical raw fermented salami products from around the world

### 17.1 Hungarian salami

Hungarian salami is generally made from pork meat. The meat used is from heavy sows which are older than 2 years, weighing around 180–200 kg. This type of meat is chosen because it contains less free water, is darker in colour and is firmer than meat from young pigs of age around 6 months. In general, starter cultures were not used in the past to make this kind of salami, but they are commonly introduced nowadays. When a starter culture is applied, a small amount of sugar is added as well to ensure proper colour and flavour development and guarantee some degree of acidification. Very few other additives are introduced, most commonly only nitrite and spices such as pepper, nutmeg and cloves. The meat is generally cut in the bowl cutter until the particles are 2–3 mm in size and then the additives are mixed with the cut meat.

Fermentation starts at low temperatures, e.g. 10–12 °C, and the temperature is kept low until an  $A_w$  below 0.95 is reached in the product, which makes it stable against *Salmonella* spp. The pH drops as a result of natural acidification to around 5.2 and from this point pH is a hurdle against *Staphylococcus aureus*. Having the combination of a pH of 5.2 and an  $A_w$  below 0.95 ensures that the product is safe from a microbiological point of view. The salami is smoked with natural smoke at low temperatures several times during the initial stages of fermentation and dried.

After around 10–14 days, mould is sometimes applied to its surface. Quite often, however, placing the salami into rooms with other moulded salami is sufficient to cause the internal house flora to grow on its surface. The presence of mould as well as a long period of drying results in the

typical flavour, which is due to compounds formed through proteolysis as well as lipolysis. In the finished product, which is commonly 90–100 days old, the level of fat is around 45% and salt is present at around 4%. The peroxide number varies between 0.6 and 0.9 and the TBA value (see Chapter 1, Section 1.9) is between 0.8 and 1.0. Because proteolytic enzymes have been active over a long period of time, the pH of the finished products is generally between 6.0 and 6.3. An  $A_w$  of 0.85–0.88 is also achieved and therefore the product is shelf stable.

## 17.2 Kantwurst (Austria)

Kantwurst is a rectangularly shaped type of raw fermented salami made in Austria. The pH value of kantwurst declines to around 4.8–5.0 within 3–4 days and therefore it is a medium–fast-fermented product. Acidification occurs owing to the introduction of starter cultures which ferment sugars into lactic acid (GDL is normally not applied). Commonly, the raw meat and fat materials are cut in the bowl cutter to a particle size of around 2–3 mm. Pork (sow meat) is predominantly utilized and up to 10% beef is occasionally processed as well. The additives introduced are salt (26–28 g per kilogram of product), nitrite, ascorbate and spices such as black pepper, garlic, coriander and caraway seed. The sausage mass should be at a temperature of between –3 and –1 °C once it has been removed from the bowl cutter. It is subsequently filled into fibrous casings with a diameter commonly of between 55 and 75 mm. The product is not tightly filled, rather it is only filled to around 80% of total capacity.

The filled sausage is then placed layer by layer into a press. The press is divided into layers by partitions made from stainless steel which are around 3–4 cm in height along their longer side. The salami are usually as long as the partitions are wide. The relatively loosely filled salami are placed in layers in the press tightly next to each other so that they do not move or stretch while they are pressed. The partitions are used to separate the layers: once a layer is full, another dividing layer of stainless steel is placed on top of it, which is then filled up with salami. Eventually, the entire press is filled with many layers of salami, each layer containing several individual pieces and, once the press is full, a thick layer of stainless steel is placed on top of the final layer. Gentle but firm pressure is then applied to the salami by tightening the two screws of the press. Finally, the press is placed into the fermentation room. During the first 2–3 days of fermentation, the screws are tightened several times so that the pressure applied to the product is continuous. During this period of time the temperature in the fermentation room is between 20 and 24 °C and the RH is around 90%. After around 4–5 days, during which time the pH has fallen to around 4.8–5.0, the product becomes sliceable and is removed from the press. Slime is commonly seen on the product as moisture cannot escape from the product whilst it is

trapped in the press. The product is washed with a weak and lukewarm salt solution (3–4%) and hung.

At this stage, the salami is already rectangular in shape as a result of being pressed. During fermentation for 4–5 days the sol inside the product has also been transformed into a gel via acidification. The product is hung in a room at a temperature of around 20 °C, a RH between 86% and 90% and under an air speed of around 0.6–0.4 m/s. As soon as the surface is dry, the product is cold smoked at 20–25 °C to avoid the growth of mould. Smoking is repeated several times over the following 2–3 days and the product is dried until around 25–30% in weight is lost. During drying, the rectangular shape becomes even more pronounced. The finished product is stable and has a pH of around 5.0–5.2 and an  $A_w$  of around 0.92. Products can be dried for a longer period, in which case they have an  $A_w$  value of around 0.88–0.89 (30% loss during drying). They are therefore shelf stable without refrigeration.

### 17.3 Lup cheong (PR China)

Lup cheong has been produced in PR China for thousands of years. It used to be made from goat and lamb meat mixed with onions, salt and pepper. Today, however, the product is made from coarsely minced pork meat, pork fat (or fatty pork meat), sugar (up to 10%), salt (2.2–2.8%), Chinese wine, soy sauce, five-spice mix (watchau (Szechwan pepper), anise, clove, cinnamon and fennel), nitrite and MSG. The main flavour is from soy sauce and the high levels of sugar, which make the sausages taste sweet. A sweet taste is desired as Asians generally do not favour an acid or sour taste in meat products.

To produce lup cheong, fatty pork trimmings are usually minced with the 8–10 mm blade and all the additives are mixed with the minced trimmings. Water is added at around 10–15% to support the formation of wrinkles during drying in the finished product. The mixed mass is filled into 24–26 mm casings and dried above charcoal for 24–48 h at 45–55 °C and a low RH (around 70%). Such intensive drying, in conjunction with high levels of  $A_w$ -reducing additives such as sugar and salt, quickly lower the  $A_w$  to 0.90 within 2–3 days. The pH always remains high as lactic acid bacteria do not play a significant role in the process; their numbers are only around  $10^3$ – $10^4$  per gram of sausage. After the initial fast reduction in  $A_w$ , the product is left for 3–4 days for further drying and equilibration at room temperature. Another result of such fast drying is that the sausage has the desired wrinkly appearance and the characteristic reddish colour with large white particles of fat. Occasionally, the product is dried even further and the  $A_w$  in the finished product can be as low as 0.75–0.8. The pH of the finished product is generally between 5.7 and 6.0.

Lup cheong is predominantly sliced diagonally, fried and consumed hot with vegetables or rice. It is microbially stable owing to the combination of

high levels of salt and sugar and the rapid reduction in  $A_w$ , made possible by filling the sausage into small-diameter casings and drying under high temperatures.

### **17.4 Cacciatore (Italy)**

Cacciatore is made primarily from lean pork meat from the shoulder and leg. In total, around 60% of the product is lean pork meat, around 10% lean beef and around 30% hard pork fat from the loin or the neck. Additives such as salt (2.8%), nitrite, ascorbate and sugar are added as well as spices. Pepper, coriander, caraway, garlic and some chilli are the spices frequently used. Starter cultures are also introduced. The raw meat and fat materials used should be slightly frozen. Most often, meat and fat materials are minced with the 4–5 mm blade and mixed with all additives until some tackiness is seen. Less often, the materials are cut in the bowl cutter until 4–5 mm particles are obtained and the mixture is slightly tacky. The sausage mass is then filled into beef runners with a diameter of 35–37 mm and dipped into a solution containing surface mould. The first stage of fermentation commences at 22–24 °C and an RH of 60–65% and lasts for 5–8 h. The product is then exposed for 2–3 days to a temperature of 22–24 °C and an RH of 90–92%. Following that, the temperature is reduced to around 18–20 °C and the RH lowered to 84–88%. Final drying and storage take place at 12–15 °C and around 75% RH until about 30–32% is lost in weight. The product is shelf stable at the end of the process at an  $A_w$  below 0.89.

### **17.5 Milano salami (Italy)**

Milano salami is made from 70–75% lean pork (90–95% CL grade) from the shoulder and 25–30% pork back fat. Salt is added at 2.8–3.2%, sugars at 5–7g per kilogram of product and spices at around 5 g per kilogram of product. The spices most commonly used are white pepper, cardamom and garlic. Red wine is frequently added as well at around 1 l per 100 kg of sausage mass. The meat to be processed should be semifrozen and the fat should be frozen. The meat and fat materials are cut in the bowl cutter to a particle size of 3–4 mm and should be at a temperature from –3 to –1 °C once the sausage mass has been produced. The sausage mass is then filled into fibrous casings of 80 mm diameter or natural casings. After filling, a netting is put over the salami and handmade nets are used for top-quality products. The fermentation process starts with tempering for around 5–8 h at 22–24 °C and 60–65% RH. Then the product is fermented at 22–24 °C and 90–94% RH for 2–3 days. The temperature and RH are then gradually lowered to 18–20 °C and 80–85% respectively. Final storage and drying takes place at 12–15 °C, an RH

of around 72–74% and an air velocity of 0.1–0.2 m/s. Mould is applied to the product. This can take place straight after the product has been filled, in which case the product is dipped into a mould-containing solution. More often, however, the product is smoked slightly (using cold smoke at 20–25 °C) and then mould is sprayed on 2–3 days later. The total loss in weight during drying is 30–34% and the product is shelf stable as an  $A_w$  below 0.89 is achieved. Milano salami only acidifies very slightly; the pH drops during fermentation to a level of around 5.2–5.3.

## 17.6 Summer sausage (USA)

Summer sausage is produced from lean beef, pork, pork fat or fatty pork trimmings. The particles of meat and fat in the finished products have a diameter of around 3–4 mm and the fat content of the product is around 30%. Additives such as salt (around 25–28 g per kilogram of product), nitrite and spices are added and black pepper, mustard seed, nutmeg, coriander and allspice are the spices most frequently used. Nitrite and starter cultures are also introduced. The sausage mass is filled into fibrous casings of 70–80 mm diameter and the product is fermented at high temperatures of around 35 °C. The pH drops quickly as a result and the final pH obtained is usually around 4.5, which is quite low but accepted by the customer. After being smoked, the salami is heated to around 58–60 °C in the core at low RH levels (around 40–50%), resulting in a semicooked product. Finally, the product is dried further until the desired weight loss has occurred.

## 17.7 Sucuk (Turkey)

Sucuk is a ring- or horse shoe-shaped delicate, heavily consumed in Turkey. It is an air-dried fermented product made from a mixture of meat and fat material originating from beef, mutton (sheep) and buffalo. In the past, however, sucuk was made from beef only. Besides spices and salt, no other additives are introduced in products produced in the traditional way. Salt is added at around 25 g per kilogram of product and nitrite is applied as well. The main spices are cumin, black pepper, fresh garlic, ginger, cinnamon and cloves, and sugar is added as well. Meat and fat materials are coarsely ground and all additives and spices are added before all the components are well mixed. Commonly, the sausage mass is left standing in the chiller overnight before being filled into beef or sheep casing of 24–28 mm diameter. The filled product is then smoked several times before being dried for 2–3 weeks. Nowadays, 0.4–0.5% of GDL is commonly added to the product to speed up fermentation and also to increase the shelf life of the product. Sucuk is still commonly produced not following the quality requirements of

EC standards, although this does not seem to affect consumer attitude to the product. Quite often, a strong garlic and cumin flavour, rather than the typical fermentation flavour is seen in the final product. Some degree of rancidity in the flavour is also accepted by the consumer. Sucuk is cut into slices, fried on both sides and primarily consumed with scrambled eggs for breakfast.

### **17.8 Chorizo (Spain)**

There are countless different types of chorizo produced in Spain and almost every region has its own version. Chorizo can be made from pork only but a mix of beef and pork is also very common. The fat content of the freshly made product is around 30% and spices such as paprika (which gives the red colour to the product) are used at fairly high levels. Other spices such as chilli (hot or less hot), garlic and pepper as well as salt (2.5%), nitrite and ascorbate are part of the product as well. The meat and fat materials are cut to around 6–8 mm in diameter before the sausage mass is filled into large-diameter pork or beef runners. Occasionally, the sausage mass is also filled into 50–70 mm fibrous casings. The product is slightly smoked after fermentation and subsequently dried to varying degrees. Some products are heavily dried until an  $A_w$  below 0.89 is obtained. Others are less thoroughly dried. Chorizo is consumed raw, fried or cooked.

### **17.9 Fuet (Spain)**

Fuet is a Catalan product from Spain and generally made only from pork. The fat content is around 30–35% and the particles of meat and fat display a size of 3–5 mm. The spices utilized such as paprika and garlic give the product a sweet and aromatic flavour. The sausage mass is filled predominantly into collagen casings of 38–46 mm diameter and occasionally into natural casings as well. Noble mould is applied to the surface and the fermented product is dried until around 30–35% in weight are lost.

### **17.10 Pepperoni (USA)**

Pepperoni in the USA is a raw sausage made from beef and pork or pork only. Products made from 100% beef must be called beef pepperoni. The loss in weight during manufacture of pepperoni is around 30%, ending up with a water:protein ratio of less than 1.6:1 and fermentation takes place primarily under the impact of starter cultures. The fat content of pepperoni is around 30–35%. To manufacture this type of salami, semifrozen meat and fat materials are cut in the bowl cutter to a particle size of 4–5 mm before salt

and nitrite are added. The final granulation is 2–3 mm. Spices, starter cultures, colour enhancers and other additives are introduced into the bowl cutter at the beginning of the cutting process. Paprika is commonly added to give a touch of red within the product. Salt is present at around 27–29 g per kilogram of sausage mass. The tacky mass is filled into easy-to-peel fibrous casings of 45–47 mm diameter. Back rolling has to be avoided during filling as this can lead to cupping of the sliced product on the pizza (see Chapter 16, Section 16.3.2). The widest filling pipe in relation to the diameter of the casing has to be used to avoid back rolling of the sausage mass.

Fermentation starts at around 24 °C and 90–92% RH for around 24 h and continues at 90% RH and a temperature of around 20 °C for another 24 h. On the third day the temperature is reduced to around 18 °C and the RH lowered to around 85–87%. Smoke is applied for 1–3 h at around 30–35 °C and the product is then dried for several hours at 50–55 °C. Drying continues at around 60 °C until the total weight loss is around 30%. The total production time of such traditional pepperoni is 5–6 days, making it basically a fast-fermented and semicooked product. Obtaining a consistent diameter in the finished product is of great importance as every single slice has to exhibit the same size. Pepperoni is also produced by following a process as described under point 17.6 applying around 35 °C during fermentation and heating the product to around 58 °C in the core before being dried at moderate temperatures until the desired loss in weight is achieved.

Cooked pepperoni is also produced on a large scale and is made within 1 day. This product is made from around 50% fine base emulsion and 50% coarse meat and fat particles. A total recipe would contain 42% beef and 8% ice to create the 50% base emulsion. Cooked pepperoni is produced by cutting lean beef with ice, salt, nitrite, phosphates and spices until a binding fine paste is obtained at a temperature of around 0–4 °C. Well-chilled or slightly frozen meat and fat materials are added to the base emulsion and cut until a particle size of 2–3 mm is obtained. The well-mixed tacky sausage mass is filled into fibrous casings of 47 mm diameter. The mass is then left to redden for 30–45 min at a temperature of around 50–55 °C and low RH. Hot smoking at 60–65 °C for 30–45 min is the next step, followed by thermal treatment at 75–78 °C with steam, or dry heat, until a core temperature of 70 °C is obtained. The fully cooked product is then showered and hung for drying, generally for between 1 and 3 days.

## 18

# Semicooked and fully cooked fermented salami

### 18.1 Manufacturing technology for semicooked fermented salami

As time is always associated with cost, and this is especially the case when products such as salami are dried and fermented, semicooked products are a happy medium between raw fermented (non-heat-treated) and fully cooked products. Semicooked fermented salami are predominantly produced following the fast-fermentation process (see Chapter 16, Section 16.3.3). The sausage mass is obtained using either a bowl cutter or a mincer–mixing system (see Chapter 16, Section 16.3.1). In finely cut products, frozen and semifrozen meat and fat materials are most commonly cut in the bowl cutter to a granulation size of 2–4 mm. The fat content of the product is around 30–35% and pork is the type of meat most often processed. However, other types of meat such as beef and lamb, or a mix of pork and beef, are processed frequently as well. Additives such as GDL (8–10 g per kilogram of product), salt (around 25 g per kilogram of product) nitrite, ascorbate and spices are introduced. Salt and nitrite are added last during mixing to obtain a small amount of sol. Even though the product is partly heat treated, starter cultures are commonly introduced into the sausage mass, in combination with sugars, to obtain a pH value of around 4.8 within 48 h of acidification. The temperature of the finished sausage mass is between approximately –3 and 0 °C. Smearing of fat has to be avoided during cutting or mincing. The sausage mass is subsequently filled into natural or fibrous casings of 48–70 mm diameter, with fibrous casings being the most common choice. A long resting time prior to filling has to be avoided as GDL hydrolyses into gluconic acid, especially on the top layers of the non-filled salami mass placed in trolleys

or tubs. Smearing has to be avoided during filling as well; the appearance of the salami is improved if meat and fat particles can be distinguished in the final product.

Fermentation of the filled product starts by conditioning for around 1–5 h at 22–24 °C and an RH of 60–70% to remove condensation water (see Chapter 16, Section 16.3.3). Following conditioning, the RH is increased to around 90–92% for the next 24–28 h to support formation of gluconic acid from GDL.

Occasionally, the temperature is also increased to 24–26 °C to speed up formation of gluconic acid. After 36–48 h, the pH value has dropped to levels of around 4.8; the sol has been denatured by the impact of acidification and turned into a gel by a pH value of 5.2. Therefore the product is sliceable. Nitrosomyoglobin has also been denatured and stabilized once the pH reaches 5.2. The next step is cold smoking. The product is smoked at 20–25 °C several times over the next 24–48 h until the desired smoke colour is obtained.

The smoked product is then thermally treated with either steam or dry heat (baking) at 70–75 °C until temperatures of around 55–60 °C are reached in the core of the product. Application of dry heat is preferred as it results in strong colour in the final product as well removing large amounts of moisture at the same time. When temperatures of 55–60 °C are obtained in the core, the outer areas of the product are almost fully cooked whilst the core remains semicooked and even partially raw. The thermally treated product is dried further at 12–14 °C and 72–75% RH for another 2–3 days and a loss in weight of around 15–20% is achieved.

Generally, the entire manufacturing process is completed so that products made on Monday are packed on Friday or Saturday of the same week. The finished product is most commonly sold as a whole piece, occasionally sliced. It is stored under refrigeration at temperatures below 4 °C even though it has a pH value below 5.2, thus being stable from a microbiological point of view. Following such a procedure results in a semicooked semiraw fermented product which still exhibits a salami character and flavour to a large degree but has been produced in a short period of time. However, several countries in the world do not permit the production of these semicooked semiraw products, insisting instead that a product is either raw fermented and dried (non-heat-treated) or fully heat treated to a temperature of 70–72 °C in the core.

## **18.2 Manufacturing technology for fully cooked fermented salami**

Fully cooked fermented salami is a salami product produced within the shortest possible time. Products produced this way are commonly used as pizza toppings or cut into small cubes to be further processed in fillings or sauces. The sliced product is often used in sandwiches as well. Fermented

and fully cooked salami is made either in the bowl cutter, in which case it has a particle size of 2–3 mm, or following the mincer–mixing system (see Chapter 16, Section 16.3.1), therefore having a particle size of 4–8 mm. In both cases, the temperature of the sausage mass prior filling must be between –3 and 0 °C to avoid smearing. As in Section 18.1, pork meat and fat materials are commonly chosen, but other types such as beef, lamb and chicken are processed as well. The fat content of the products is between 30 and 35%. Acidification generally takes place through the addition of GDL and around 8–10 g are introduced per kilogram of sausage mass. Starter cultures are not added. Salt (around 25 g per kilogram of product), nitrite, ascorbic acid or ascorbate (0.5–0.7 g per kilogram of product) and spices are the other additives introduced into the sausage mass. As in Chapter 16 (raw fermented salami), nitrite must not be added to the sausage mass at the same time as ascorbic acid. The sausage mass is most commonly filled into fibrous casings of 60–90 mm diameter. After the conditioning phase is completed, fermentation takes place at 24–26 °C and an RH of 90–93% in order to speed up formation of gluconic acid for a quick reduction in pH value to around 4.6–4.8. The decrease in pH value is achieved within 36–48 h and curing colour is stabilized as well because the pH value drops below 5.2 and nitrosomyoglobin is denatured via acidification. The acidified product is placed in a smoking chamber and generally hot smoked at temperatures between 65 and 70 °C until the desired smoke colour is obtained. Occasionally, the entire thermal treatment of the product takes place under the impact of hot smoke at temperatures between 76 and 80 °C until a temperature of 70 °C is reached in the core. It is also common, once hot smoking is completed, for dry heat to be applied at 76–80 °C until an internal temperature of 70 °C is reached. The hot product is showered for a short while to avoid the formation of wrinkles and is then placed in the chiller. As a result of fermentation for 2–3 days as well as the dry and hot conditions during smoking and thermal treatment, the total loss in weight during the entire manufacturing process is only around 15% and the manufacturing process itself is completed within 4–5 days. The chilled product is most often sold in sliced form for sandwiches and pizza toppings. Modified-atmosphere packing is the type of packaging usually chosen with vacuum packing also being occasionally used.

Owing to acidification, the fully thermally treated product still has a slight typical salami taste and flavour. A large majority of fully cooked fermentable salami products are sold under heavy price constraints. Therefore manufacturers try to lose as little weight as possible from the salami during production.

## 19

### **Non-fermented salami**

Non-fermented sliceable salami (NFSS) strictly speaking has nothing in common with salami, as salami is by definition a non-heat-treated product. Unlike salami, NFSS products do not acidify and water is even added during the manufacturing process, rather than being removed through drying. NFSS can be shelf stable without refrigeration but are often stored at temperatures at or below 4 °C. Large or small visible particles of lean meat as well as small particles of fat are the basic raw ingredients of NFSS and all the ingredients are held together in a finely cut base emulsion. Finished products can be categorized into finely cut or coarse-minced products and all products are filled into non-waterproof casings such as cellulose, fibrous or textile casings.

#### **19.1 Selection and preparation of raw materials**

NFSS are predominantly made from pork. They are occasionally made from beef and lamb, however, for consumers who do not consume pork for religious reasons. Pork meat from sows is the preferred raw material as it is darker in colour, contains less water and in most cases is less expensive than pork from younger pigs. The meat to be processed must have a low bacteria count and a value between  $10^2$ – $10^4$  per gram is optimal. The fat or fatty trimmings to be used must not be rancid and their microbiological status should be comparable with that of lean meat. It is preferable to use hard fat containing a low number of unsaturated fatty acids (such as fat from the loin, neck or fatty bellies), as the risk of smearing during cutting or mincing is increased

if soft fat from shoulder or leg is used and clearly cut particles of fat should be visible in the finished product.

95% CL-grade lean beef is commonly used for the production of a fine base emulsion, which acts as the glue within the product between the individual pieces of meat and fat. Using DFD beef to make the base emulsion should be avoided if possible, as this type of meat can affect colour development negatively but, if some of the beef processed is of DFD character, there will be no significant disadvantage. The amount of base emulsion within the total product is generally between 20% and 30%. In an all-pork product, the base emulsion can be made from lean pork meat. It is not a significant disadvantage to have some PSE-character pork as the visible particles of meat. However, the concentration of PSE pork within the total amount of pork used should not exceed 10–15%. Commonly meat from cuts such as shoulder, neck and rump are used and these cuts are quite dark in color, thus hiding a small amount of PSE pork. In high-quality non-fermented salami, meat from the leg is processed as well. If this type of meat is used, once again, sow meat is the preferred choice. Boar meat should not be used as most people are very sensitive to the smell of boar, caused by the male hormone androstenone testosterone as well as scatol and find it unpleasant.

All meat materials to be processed must be stored at temperatures below 4 °C to avoid or delay growth of bacteria such as *Staphylococcus aureus*, *Pseudomonas* spp. and *Salmonella* spp. The meat and fat materials to be processed for finely cut products are stored in the freezer. Just as in the production of raw fermented salami, fat is primarily processed fully frozen whereas meat is processed semifrozen. The temperature of the fat to be processed for finely cut products should be around –18 °C whereas the meat should be at a temperature of around –5 °C. Pork fats from the loin and neck are also processed chilled as they are hard fats containing a small amount of unsaturated fatty acids. This chilled fat is precured and stored in the chiller at a temperature below 4 °C. Precuring hardens the fat even more.

## 19.2 Selection of additives

NFSS contains very few additives as substances such as carrageenan, soy protein, colours, starch or any other filler (binder) are not introduced. The only additives usually applied are phosphates, salt, nitrite, colour enhancer and spices. Salt is the most basic additive and is applied at levels of between 18 and 20 g per kilogram of product. The main reasons for adding salt to NFSS are its contribution to flavour and its contribution to activating protein in the manufacture of the base emulsion. Salt is not a hurdle against microbiological spoilage as it is in raw fermented products. Nitrite is added to ensure that a stable strong curing colour develops and also for its contribution to curing flavour. The level of nitrite added has to be adjusted according to the maximum level permitted in the finished product in food standards of the

respective countries. Around 60% of the nitrite added to the uncooked product is used for the development of the curing colour and flavour and a fair amount is also lost during heat treatment. Some nitrite is oxidized to nitrate during processing and is therefore not available after thermal treatment to stabilize curing colour. The enzyme responsible for the reduction of nitrate to nitrite (nitrate reductase) is destroyed by temperatures above 68 °C.

Colour enhancers are commonly added, ascorbate or ascorbic acid being those usually chosen. The level of ascorbic acid or ascorbate is normally around 0.5–0.7 g per kilogram of total mass. Care has to be taken that colour enhancers based on ascorbic acid do not come into direct contact with nitrite as highly toxic nitric oxide (NO) would form and nitrite would not be present afterwards for the formation of curing colour. NO is extremely toxic and presents a serious health risk.

Phosphates are applied at 5–6 g per kilogram of base emulsion and the finely cut tacky mass formed acts as an effective binding glue. The type of phosphates applied are cutting phosphates (see Chapter 5, Section 5.1.2). These contain a large proportion of short-chained phosphates, which activate protein rapidly. Spices and herbs are introduced according to the manufacturer's recipe. Garlic, pepper and coriander are often the main spices introduced. In some products, visible spices such as cracked black pepper, or green peppercorn, are used for contribution to the appearance of the final product.

### **19.3 Manufacturing technology**

To produce NFSS, particles of fat and lean meat of various sizes are mixed together and several different manufacturing methods are commonly practised. In products with large lean pieces of meat, precuring is recommended as the time for colour development in the finished product is then significantly shortened.

#### **19.3.1 Precuring of meat and fat materials**

To precure the lean meat (which is generally pork of 95% CL grade but can also be lean beef in non-pork products), all the necessary nitrite and salt are first added. Around 18–20 g of salt and around 150–250 ppm of nitrite are applied per kilogram of meat. The particles of meat are around 20–40 mm in diameter. The meat and additives are then mixed well to ensure even distribution of salt and nitrite and the mixture is left to stand in the chiller for colour development. Occasionally, ascorbate is added as a colour enhancer as well at around 0.5 g per kilogram of lean meat. When fatty pork belly is used as the visible meat, the belly meat is cut into smaller pieces and precured in the same way. The advantage of precuring is that, once the material is actually utilized for the production of NFSS, all colour development in larger pieces of meat has already taken place. The introduction of salt also causes fibre

structures in the lean meat to swell. Therefore water present in the muscle tissue does not leak out and the precured lean meat suffers no weight loss. Another benefit of precuring is that the introduction of salt, and nitrite, slows down bacterial growth on and in the meat.

The fat used in minced products is commonly precured as well but not for colour development as no myoglobin is present within fat. The addition of salt and nitrite slows down bacterial growth on the fat and therefore increases its shelf life under chilled conditions. The addition of salt to materials such as lean meat and fat also increases its firmness thus reducing the risk of fat smearing during mincing. Cleanly cut particles of lean meat are therefore present in the finished product.

### **19.3.2 Manufacture of the base emulsion**

The base emulsion is the binding glue between the particles of fat and lean meat in the finished product. A base emulsion is generally produced from lean beef (95% CL grade), water and ice and additives such as salt, nitrite and phosphates. In most cases, the level of extension is 50% and, for example, 33 kg of water and ice are added to 67 kg of beef to obtain 100 kg of base emulsion. For 100 kg of base emulsion, around 20–25 g of nitrite (200–250 ppm per kilogram of base emulsion), 500–700 g of cutting phosphate and 2 kg of salt are added. The process starts by placing the beef in the bowl cutter and cutting it under a medium–fast speed. Phosphates, around 70% of the total ice and water and the nitrite and salt are added. The relative amounts of ice and water added at this stage are dependent on the temperature of the lean meat. A temperature of 0 °C is desired before the cutter can be switched to a fast knife speed. In the case when chilled meat is processed, basically all the 70% is ice. Some water can be included, however, when the beef processed is slightly frozen. All the materials are cut at a high knife speed until the temperature is around 4–6 °C. At this point, the remaining 30% ice is added.

Ice is added rather than water at this point to reduce the temperature of the base emulsion within the cutter to around 0 °C. All the materials are then cut at a high knife speed until they are at a temperature between 2 and 4 °C, to complete the process. At the end, a highly tacky, shiny and finely cut emulsion is obtained. The temperature range during the process is purposely kept between 0 and 4 °C as activation of protein is most effective at these temperatures and bacterial growth is controlled as well. The base emulsion can be stored in the chiller at temperatures below 4 °C for several days as long as the mass was at a temperature below 4 °C when it was removed from the bowl cutter.

The quantity of salt and nitrite added to the base emulsion can be the quantity required for the total product mass (the mass including the fat and meat subsequently to be added to the base emulsion). For example, if 100 kg of total product contains 25 kg of base emulsion, 25 kg of fat and 50 kg of precured lean meat, then the amount of salt and nitrite is added in the 25

kg of base emulsion is that required for 50 kg of raw materials (25 kg of base emulsion as well as 25 kg of fat; no salt and nitrite is required to be added for the precured lean meat). In this case, 1 kg of salt ( $50 \text{ kg} \times 20 \text{ g}$  per kilogram of base emulsion), 12.5 g of nitrite ( $50 \text{ kg} \times 0.25 \text{ g}$  per kilogram of base emulsion) and around 175 g of phosphates ( $25 \times 7 \text{ g}$  per kilogram of base emulsion) would be added to 25 kg of base emulsion. The 25 kg of base emulsion would be produced from 17 kg of lean beef and 8 kg of ice or water. If the fat had been precured as well, salt and nitrite would only be applied for 25 kg of base emulsion.

### **19.3.3 Non-fermented cooked salami with small particles of fat and meat**

A product with small particles of fat and meat is obtained commonly using one of two possible methods. One method is to cut the frozen fat and semifrozen meat material in the cutter whilst the other is to obtain the desired particle size by mincing the meat and fat materials. The particle size of fat and meat in this type of product is most often between 2 and 3 mm.

A finely cut salami is produced in a way quite similar to a sliceable raw fermented salami, at least in the initial stages. A typical recipe contains 25–30% base emulsion, 25% pork back fat and around 45–50% lean meat, most commonly pork. Frozen fat is placed in the bowl cutter and cut with sharp knives for a short while until particles of around 8–10 mm are obtained. Semifrozen lean meat is added to the fat and all the materials are cut at a medium–fast knife speed until the desired granulation is almost reached. As in the manufacture of finely cut salami, it is important for the frozen materials to flow freely whilst being cut. Therefore the bowl cutter should only be around 50% full so that materials are not pushed around or squeezed during cutting. Once the desired granulation size is almost reached, the speed of knives is reduced to around 300–500 rev/min and the base emulsion is evenly added into the cutter. All the spices are added and salt (and nitrite) is (are) also introduced at the level required for the meat and fat materials, taking into account that the base emulsion already contains salt and nitrite (spices and colour enhancers are added at a level appropriate for the total amount of sausage as the base emulsion does not contain these already). While the base emulsion and additives are added, a small amount of cutting continues to take place until the desired granulation is obtained.

If possible, the cut sausage mass is subsequently mixed in the bowl cutter at a very slow knife speed. The application of vacuum during mixing is also advantageous. The vast majority of air pockets are removed by mixing under vacuum and a shiny as well as compact sausage mass is obtained. Removing oxygen also helps to develop the curing colour in the final product. The final temperature of the sausage mass prior to filling is around 0 °C, which prevents smearing of fat during filling. It can be beneficial to cut the frozen fat and semifrozen meat as the finished cooked product then looks more like a

salami than if the mass is minced (see below). On the other hand, however, not all fat and meat particles in the finished product are exactly of the same size if the material is cut as they are if the sausage mass is minced.

Another method of obtaining a small-particle NFSS is to place the base emulsion into the bowl cutter and add chilled (or frozen) fat as well as chilled pre-cured lean meat to the base emulsion. All the materials are cut under a slow speed and spices, colour enhancer, salt and nitrite are added. The level of spices is calculated according to the total batch size and the level of salt as well as nitrite is calculated according to the quantity of non-precured meat and fat present, as the base emulsion already contains salt and nitrite. Quite commonly, however, precured chilled lean meat is processed and therefore the level of salt and nitrite added is reduced to a level appropriate for the quantity of fat only. If all meat and fat materials are precured, then of course no salt or nitrite is added.

The entire mass is cut for a few turns in the bowl cutter to ensure an even distribution of the fat, meat and additives. Then the sausage mass is removed from the cutter and minced with the 3–4 mm blade using a double set of knives. The knives and blades inserted into the mincer are placed in the following sequence: precutter → knife → 13 mm blade → knife → desired blade (3–4 mm) → fixation ring. Care has to be taken that all fittings are tightened properly and a clean cut is obtained without smearing of fat. The speed of mincing is moderate so that the sausage mass passes comfortably through the mincer without being pushed. Commonly, the minced sausage mass is placed afterwards either into a paddle mixer or into the bowl cutter to be mixed for a short while under vacuum. After mixing, the final temperature of the sausage mass is between 4 and 8 °C but can be lower if frozen fat is utilized to support a clean cut. The advantage of mincing the entire sausage mass is that every single fat and meat particle is of the same size in the finished product.

#### **19.3.4 Coarse-minced–mixed cooked salami**

The production of coarse-minced NFSS can be achieved in several different ways. One of them is to place the base emulsion in the bowl cutter and to add fat, which is mostly frozen. Cutting commences at a medium–fast knife speed, and salt and nitrite are added at an appropriate level for the amount of fat present (unless the meat to be added later is not precured, in which case the levels of salt and nitrite need to be higher). Spices are introduced at a level appropriate for the total batch size. The fat is then cut to the desired granulation, which is commonly around 3–5 mm. Afterwards, minced lean meat (8–20 mm blade), which has been precured, is gently mixed in, sometimes under the impact of vacuum.

Large amounts of coarse NFSS are manufactured using another method. This involves placing the base emulsion in the bowl cutter and adding chilled, frozen or even precured chilled fat. All the ingredients are cut for a short

while until minceable pieces of fat are obtained. Additives such as spices, colour enhancer and nitrite are added to this mass. The base emulsion fat mass is then removed from the bowl cutter and commonly minced with the 3–6 mm blade at a moderate speed utilizing sharp mincer knives to obtain a clean cut without smearing. Once mincing is completed, the mass is placed into a paddle mixer and minced precured lean meat, frequently minced with the 8–13 mm blade, is added. All the materials are mixed gently for a short while, possibly under a vacuum. This process ensures, firstly, that all particles of fat are of the same particle size in the finished product and, secondly, that the particles of fat are smaller than the particles of lean meat which makes a good contrast in the final product.

By following a recipe containing only around 20% base emulsion, 20% fat and 60% lean meat, a very attractive and high-quality product is obtained. Visual spices such as cracked pepper or green peppercorn are regularly mixed into coarse NFSS as well.

### **19.3.5 Filling**

The sausage mass obtained is filled subsequently into permeable casings. Fibrous casings of diameter between 60 and 120 mm are predominantly used. Casings made from linen, other textiles, collagen or cellulose are also used in high-quality products and a small percentage of products are filled into large-diameter natural casings, such as beef bung. Fibrous casings are generally soaked prior to use in lukewarm water for around 30–45 min and any other type of casing utilized should be treated according to the manufacturers' recommendations. Filling takes place under a vacuum to eliminate all residual air trapped in the sausage mass. This ensures that an air-free product with good slice coherency is obtained. The application of a vacuum during filling also supports the formation of a strong curing colour. The filling speed is largely determined by the diameter and type of casing used as well as the particle sizes of the meat and fat. Generally, larger-diameter casings are filled at a slower speed than small-diameter casings. Products with large pieces of visible meat should also be filled at a moderate speed. As mentioned before, the speed of filling has to be adjusted so that smearing is avoided and fat and meat particles are clearly visible in the filled product. The casings are filled tightly and clipped, or tightly closed with a string. Care has to be taken that the clip does not cut the casing as it is secured around the casing. Even the tiniest of cuts made to the casing cause it to burst during heat treatment. Clips attached too tightly can also cut the casing and, as a result, the hung sausage will drop during thermal treatment.

### **19.3.6 Drying, smoking and cooking**

Once filling is completed, drying is the first step in thermal treatment. Drying takes place at around 60–65 °C and a low RH (around 40%) for between

approximately 30 min and 1 h. The drying time has to be adjusted according to the diameter of the casing and, generally, products filled into a large-diameter casing require longer drying. The filling level of the smoking chamber has an impact on the speed of drying. Moisture is removed at a slower rate from each individual piece of product when the chamber is full compared with when the chamber is only half full. Temperatures between 60 and 65 °C speed up the development of curing colour tremendously and, once the surface of the casing is dry and a strong red curing colour is seen, smoking can commence. The period of drying is extended when non-precured lean meat is utilized as show-meat, especially if the meat was minced with a 13–20 mm blade. This is because, when non-precured meat is used, the drying process is the period of time in which curing colour develops. Products filled into a large-diameter casing and containing large pieces of non-precured meat (13–20 mm) require a drying period of up to 2 h to ensure full and proper colour development in the core of the product. In order to avoid such prolonged periods of drying, however, precured lean meat is frequently used as the show-meat. Whatever the type of meat used, curing colour has to be fully developed before smoke is applied.

Smoking is the next step and the temperature applied is between 65 and 75 °C at an RH of around 50–70%. Smoking continues until the desired smoke colour is seen on the product. Generally, it lasts for 1–2 h but strongly smoked products, filled into large-diameter casings, can be smoked for up to 3 h. Upon completion of smoking, the product is either fully cooked with steam or baked with dry heat. Final thermal treatment with steam, applying temperatures of 76–80 °C so that a core temperature of 72 °C is reached, completes the process and the cooked product is showered for a few minutes to avoid formation of wrinkles during cooling. NFSS can also be treated with dry heat at 78–80 °C to reach temperatures up to 72 °C in the core and this is another method frequently practised. Cooking the product with steam results in a paler colour on the surface than cooking with dry heat as steam washes off some of the smoke applied to the surface during smoking. Applying low levels of moisture during all processing steps such as drying, smoking and cooking, on the other hand, results in a lovely colour as well as a strongly flavoured product. Products thermally treated with dry heat at the end of the process are either showered for a few minutes to avoid the formation of wrinkles or left unshowered when a natural-looking wrinkly product is desired.

Quite often, finished products are dried for another 7–21 days at 12–14 °C and an RH of around 72–74%. This is so that they lose more weight despite the fact that the application of dry heat during the cooking period has already removed large amounts of moisture. Drying of the product after thermal treatment reduces the  $A_w$  to around 0.92 which makes the product shelf stable without refrigeration because Enterobacteriaceae such as *Salmonella* spp. require an  $A_w$  above 0.95 to survive and spore-forming bacteria such as *Clostridia* spp. require an  $A_w$  above 0.95. In addition, bacteria which could

form toxin at an  $A_w$  below 0.92, such as *Staph. aureus*, are destroyed when temperatures of 72 °C are reached in the core of the product during thermal treatment.

### 19.3.7 Packaging and storage

The type of packaging and especially storage temperatures used vary significantly, depending mainly on whether the product is non-dried, partially or fully dried and whether it is sold as a whole piece or sliced. Products sold as whole pieces which have not been dried any further after thermal treatment (non-dried products) are generally vacuum packed and stored below 4 °C, as their  $A_w$  is not safely below 0.95. Vacuum packing prevents the growth of aerobic spoilage bacteria as well as mould and also avoids any further loss in weight. The product is then generally sliced in the shop prior to being sold. Non-sliced products which have been dried further after thermal treatment (partially dried products) have an  $A_w$  between 0.92 and 0.93 and are also commonly vacuum packed. These are also commonly stored refrigerated even though there is no need to do this because the  $A_w$  value of less than 0.95 stops the growth of bacteria such as *Salmonella* spp. as well as germination of spores. A small number of these semidried products are stored at room temperature and, as long as no condensation water formed during packaging, there is no problem with this type of storage. Condensation water, however, is generally not a problem in vacuum-packed or modified-atmosphere-packed non-cut or non-sliced products. This is because they are usually warm (at 12–14 °C) when they leave the drying room and hold more moisture than the level of RH in the packing area itself (see Chapter 4, Section 4.12). Some non-sliced products are dried for such a long period of time that the  $A_w$  drops to a level of, or below, 0.89, which makes the product microbiologically stable from an  $A_w$  point of view as bacteria such as *Staph. aureus* do not produce toxin at  $A_w$  values at or below 0.89. These fully dried non-sliced products are also commonly vacuum packed and, as long as no condensation water forms during packing, they can be stored at room temperature. Semidried and fully dried products, despite being microbiologically stable without refrigeration, are frequently stored chilled at around 4 °C just so that there is another hurdle in place against possible bacterial growth. Care also has to be taken that the packaging foil used has high-moisture-barrier characteristics.

The situation is different if the product is sliced before being packed. Non-dried sliced products are always stored at temperatures below 4 °C to delay, or inhibit, bacterial growth of any bacteria introduced on to the product during the slicing process. Slicing of semidried or fully dried salami carries the risk of formation of condensation water. This is especially the case if the product to be sliced was placed in the freezer or in a tempering room at temperatures between approximately –2 and 0 °C to increase sliceability of the product before slicing. The slicing room has a significantly higher temperature than the cooled product and therefore condensation water is

likely to form when the product is brought from the tempering room or freezer. Condensation water on the surface of a salami represents an  $A_w$  of 1.00 and spores as well as bacteria can grow as a result once they have access to condensation water regardless of the internal  $A_w$  of the product. As soon as condensation water forms,  $A_w$  is not present any longer as a hurdle and sliced products must be stored at temperatures below 4 °C to avoid bacterial growth. Semidried and, in particular, fully dried products are firm in texture. They are occasionally sliced without being cooled beforehand (i.e. they are taken straight from the drying room to the slicing room). If this is the case, formation of condensation water is avoided but the sliced products are still commonly stored under chilling conditions to avoid bacterial growth, as bacteria may have been introduced during the slicing process itself.

#### 19.4 Summary of critical production issues

- 1 The meat and fat material used should show a low bacteria count, between  $10^2$  and  $10^4$  per gram of product.
- 2 The fat processed should not be rancid and hard fat, low in unsaturated fatty acid, is preferred.
- 3 The base emulsion should have a maximum temperature of 5 °C.
- 4 Sharp bowl-cutter knives are essential when producing cut products. The fat in minced products must not smear during the mincing process.
- 5 Precuring of the meat materials used for show-meat is recommended.
- 6 The product should be tightly filled into non-waterproof casings under a vacuum and subsequently dried at around 60–65 °C, smoked at 65–75 °C and thermally treated to a core temperature of 72 °C predominantly by applying dry heat at 76–80 °C.
- 7 Products thermally treated with dry heat are dried until an  $A_w$  of 0.92–0.93 is obtained, which makes the products shelf stable without refrigeration. This is because all vegetative pathogens able to survive at an  $A_w$  below 0.92 have been destroyed during heat treatment. Products which are dried until an  $A_w$  of 0.89 or below is reached are fully shelf stable as surviving bacteria of *Staph. aureus* do not have sufficient free water for the production of toxin. Formation of condensation water during packaging of the product is to be avoided in products that are not stored refrigerated.
- 8 Steam-treated and non-dried products are vacuum packed and stored refrigerated at a temperature below 4 °C.
- 9 Most sliced products, regardless of internal  $A_w$ , are vacuum packed and stored at a temperature below 4 °C as the product may have been contaminated during slicing.

## 20

# Typical non-fermented salami products from around the world

### 20.1 Polish salami (Austria)

Polish salami in Austria contains around 30% base emulsion, 25% fat or 35% fatty pork belly and around 40% of lean precured pork. The base emulsion is generally cut together with the fat, or fatty pork belly, in the bowl cutter for a few turns and spices such as garlic, pepper and coriander are added. Salt (18–20 g per kilogram of product) and nitrite are introduced into the base emulsion–fat material at a suitable level to cover the non-precured fat material whilst no salt would be added in case the fat material was precured as well. All these materials are minced with the 4–6 mm blade while the precured lean pork is minced separately with the 13 mm blade. Both minced materials are then mixed together in paddle mixers and commonly filled into 75–90 mm fibrous casings. Visible spices such as black cracked pepper or green peppercorns are introduced during mixing as well. Green peppercorn in brine has to be washed and drained before being introduced into the sausage mass. This is because the peppercorn brine is acidic and would interfere with binding, causing the added peppercorns not to be effectively bound. The filled product is then dried at 65–70 °C for around 1 h, smoked at 70–75 °C for 1–1½ hours and finally cooked with dry heat at 80 °C until a temperature of 70–72 °C is reached in the core. After a short shower, the product is placed in the chiller. The majority of Polish salami is stored afterwards at a temperature below 4 °C as it is not shelf stable. Some producers dry the thermally treated product at a temperature of 12–15 °C and an RH of 72–75% until an  $A_w$  of around 0.92 is obtained, which makes the product shelf stable without refrigeration if packed as a whole piece, avoiding formation of condensation water. Polish salami is also occasionally steam cooked after

smoking. If that is the case, the steamed products are always stored refrigerated as further drying normally does not take place.

## **20.2 Cheese salami (Austria)**

A cheese salami is more or less the same as Polish salami except that 20–25% cubed cheese is added to the sausage mass. The type of cheese regularly applied is one with a high melting point such as Swiss Emmental. The cheese is cut into cubes of  $1 \times 1$  cm before being mixed into the mass. The cheese chosen must not melt during thermal heat treatment at around 70–72 °C.

## **20.3 Kransky (Slovenia)**

Kransky is a product produced all over the world and it can be found in countless different shapes and forms. Basically, the product consists of 30–35% base emulsion, 25–30% fat or 35% fatty pork belly and around 30–40% precured lean pork. As in the manufacture of Polish salami, the base emulsion is cut with the fat, or fatty pork belly, in the bowl cutter for a few turns and all additives and spices are introduced. The main spices utilized are black pepper, garlic, coriander and nutmeg. Nitrite and salt are added and the level of salt in the finished product (total mass) is 1.8–2%. All these materials are minced with the 4–6 mm blade whilst the lean precured pork is minced separately with the 8–13 mm blade. Both minced materials are gently mixed together in paddle mixers while maintaining the particle size of minced fat and meat materials. The sausage mass is filled into 26–30 mm hog casings and the casings are linked to obtain pairs of around 150–200 g. The product is subsequently dried at 60–65 °C for around 20–30 min, smoked at 65–70 °C for 20–40 min and finally cooked primarily with steam at 76–78 °C up to a temperature of 70 °C in the core. A tastier product can be obtained if the final heat treatment is achieved by the application of dry heat at around 78 °C instead of steam cooking. The cooked product is showered for 5–10 min before being placed in the chiller at a temperature below 4 °C. Once fully chilled, the product is vacuum packed for further storage. Kransky is consumed hot and can be heated by placing the product into hot, but not boiling, water until the sausage is hot, or it can be grilled on a barbecue. From a food safety point of view, kransky can be consumed cold as well because the product is fully cooked and stored below 4 °C to avoid bacterial growth. However, the hot state is by far the preferred choice.

## 20.4 Vienna salami (Austria)

Pork back or neck fat is the preferred fat material used to make Vienna salami. To make this type of salami, frozen fat and lean semifrozen meat are cut in the bowl cutter using sharp cutter knives so that they are cut cleanly. The meat and fat are cut first until a granulation of around 4 mm is obtained. The bowl cutter is only around 50–60% full (50–60 kg of meat and fat in a 100 l bowl) at this point as the frozen and semifrozen materials have to flow freely without being squeezed. The base emulsion as well as all the required additives and spices are added, and all the ingredients are mixed well at a slow knife speed until a tacky mass is obtained. As the meat and fat materials are not precured, salt and nitrite are added for the amount of meat and fat materials processed, whilst spices are added for the total mass including the base emulsion. Colour enhancer is also introduced at a level appropriate for the total mass including the base emulsion. The level of salt in the finished product is around 1.9–2.0%. During mixing, the entire mass is cut even further and a final particle size of 3 mm is obtained. Another common method is to place all materials such as base emulsion and fat (precured or frozen) as well as precured lean pieces of pork in the bowl cutter and to cut them for a few turns whilst all additives and spices are added. The mass is removed from the bowl cutter and minced with the 3 mm blade. A clean cut has to be obtained during mincing and smearing of fat is to be avoided. The minced sausage mass is commonly then gently mixed afterwards under a vacuum. Vienna salami contains around 35% base emulsion, 25% fat and 45% lean precured pork. Occasionally, precured fatty trimmings of 75% CL grade are used as a substitute for lean meat and fat. The sausage is filled into fibrous casings of 75–90 mm diameter, dried, smoked and thermally treated as in the manufacture of Polish salami. Most Vienna salami is baked by the application of dry heat at the end of thermal treatment rather than cooked with steam. Whichever method is used, a core temperature of 70–72 °C is reached. Commonly, the product is subsequently dried at 12–14 °C and an RH of 72–74% until an  $A_w$  of 0.92 is obtained which intensifies flavour, colour and sliceability.

## 20.5 Cabana (or cabanossi) (Austria and Australia)

Cabana in Austria is a high-quality product made from 30–35% base emulsion and 25% fat. The remaining 40–45% is precured lean meat of 90–95% CL grade. Sometimes, fatty pork bellies of 70–75% CL grade are used and these contain all the fat and lean meat material required. Most commonly, all materials such as base emulsion, fat and lean meat as well as fatty pork bellies are mixed in the bowl cutter for a few turns, and additives, salt and spices are introduced. The mass is removed from the cutter, minced with the 4–6 mm blade and most commonly filled into 24–30 mm collagen casings.

Filled sausages vary in length but are mostly between 20 and 25 cm. The first step in their thermal treatment is drying for 15–20 min at a low RH (around 40–50%) and 60–65 °C. Smoking then takes place at 65–70 °C for 20–30 min followed by application of steam or dry heat at around 76–80 °C until a temperature of 70–72 °C is obtained in the core. Most thermally treated products are showered for a few minutes to avoid wrinkles in the finished product before being placed in the chiller. Products treated with dry heat at the end of thermal treatment are frequently dried at 12–14 °C and 72–74% RH until an  $A_w$  of around 0.92 is reached. They are then vacuum packed and are shelf stable without refrigeration. On the other hand, products which have been steam cooked are commonly not dried any further. They are vacuum packed once chilled and stored below 4 °C. Cabana in Austria is consumed cold (and not reheated) with sour dough bread.

Because cabana in Australia is a very price-competitive product, the product is usually not smoked. Smoke flavour is frequently introduced into the sausage mass to obtain a smoke-flavoured product instead. The base emulsion is commonly also not made from beef and ice; an emulsified sausage mass, such as a frankfurter, serves instead as a base emulsion. Offcuts from other cured and cooked meat products and reject ham products are also used as visible show-meat, together with fatty precured pork and mutton trimmings. Very economical cabana consists of 60–70% of base emulsion (in most cases a low-cost frankfurter mass) and 30–40% of bacon and ham offcuts obtained during the slicing process of those products. The offcuts partially or fully replace fat and lean meat within the finished product. The sausage mass is filled into collagen casings of 26–30 mm diameter and steam cooked only to an internal temperature of 70 °C by applying steam at 76–80 °C. The thermally treated product is showered and chilled before being vacuum packed. It is always stored at a temperature below 4 °C as no further drying takes place.

## 21

### Spreadable raw fermented sausage

Spreadable raw fermented sausage is not that common in some parts of the world but is enjoyed daily in others. It is usually consumed on a slice of bread just like other spreadable meat products such as liver sausage. It is generally mildly flavoured and materials such as wine or rum are occasionally introduced for flavouring purposes. Spreadable raw fermented sausage exists in two distinctive forms: one is a very finely cut product whilst the other is coarse minced. Both products are made from raw meat and fat materials and are consumed raw. They should also both be easily spreadable. There is also a major difference between raw fermented spreadable sausages produced on a small scale and products produced on a large scale. Products produced on a small scale and sold in a butcher's shop are commonly sold within a few days of production and this type of raw sausage is usually a non-acidified product. On the other hand, products manufactured by large companies on a large scale and sold in supermarkets are frequently acidified. These products usually have a pH between 4.9 and 5.4 and the pH acts as an effective hurdle against microbiological spoilage. This is necessary as the product is not sold as quickly as it would be in a butcher's shop.

#### 21.1 Selection of raw materials

The vast majority of spreadable fermented raw sausage is produced from pork. However, any fatty meat such as beef or lamb can be used as well. As in the production of any type of raw sausage, the bacteria count of the meat and fat material used should be as low as possible and values of  $10^2$ – $10^3$  per gram of material are optimal. High numbers of unwanted bacteria originating

from the meat or fat itself such as *Pseudomonas* spp., coagulase-positive *Staphylococcus* spp. and Enterobacteriaceae can create problems during fermentation and/or shorten the shelf life of the product. This is especially significant in the manufacture of raw fermented sausage as the product is never heat treated in any way. The pH of the meat processed should be a maximum of 5.8 as high pH values reduce the effectiveness of nitrite as a microbiological hurdle in the product. Using meat with a low pH value is even more important when the product is to be filled into waterproof casings as no moisture is lost during processing when this type of casing is used.

When beef is the only meat material used, care has to be taken if all material is of DFD character (see Chapter 4, Section 4.1). Meat with a high pH such as DFD-character meat (or matured pork) has an increased WHC. The stronger electrostatic repulsive forces in meat with a high pH create larger gaps between the actin and myosin in the meat and therefore the release of moisture during drying is much slower. The development of curing colour is also less successful if the meat is at a high pH. At a lower pH the concentration of undissociated nitrous acid ( $\text{HNO}_2$ ) is higher and more nitric oxide (NO) forms, resulting in a stronger curing colour (see Chapter 7, Section 7.3). A further disadvantage of meat with a high pH is that the risk of microbiological spoilage is greater as most bacteria grow more quickly at higher pH values. DFD-character meat also never fully acidified during rigor mortis and therefore higher levels of sugar or GDL have to be added to achieve the desired drop in pH value in semi-acidified or fully acidified products when this type of meat is used.

The fat to be processed must not be rancid. Hard fat from the neck or loin is preferred as fat with a low number of unsaturated fatty acids has a higher melting point and therefore does not melt to such a great degree during processing. It is common practice, however, that soft fat, with high levels of unsaturated fatty acids (from the leg or shoulder), is also used and generally no problems are caused by using a mixture of hard and some soft fat. The softer texture of fat with elevated levels of unsaturated fatty acids is to some degree even desired, especially in finely cut spreadable raw sausage. Cutting the meat and soft fat materials intensively creates a large surface area which helps to make the finished product spreadable and to ensure that spreadability is maintained during fermentation and storage. For coarsely minced products, hard fat is preferred as less smearing occurs during mincing. Fatty pork bellies of 50–60% CL grade are often used as raw material as they contain both lean meat and fat. Care has to be taken that no glands, bloody tissue or abscesses are present in the meat or fat materials used as there would be a risk that microbiological stability and shelf life of the products would be compromised. Meat and fat, or fatty material from sows, are very suitable. The lean sow meat is dark in colour, contains less water than muscle tissue from young pigs and is generally less expensive than normal pork meat.

The level of fat within a raw fermented sausage product varies and is commonly between 35% and 55%. No water is added to the product during

the processing. In both finely cut and coarsely-minced products, a level of fat below 25% causes the product not to be sufficiently spreadable. If the level of fat is too low, some degree of binding occurs, which reduces spreadability of the product.

## 21.2 Selection of additives

Salt is generally added at a level of between 24–26 g per kilogram of sausage and contributes to flavour and taste. To a certain degree it also lowers the  $A_w$  in the product. In raw fermented spreadable sausage, salt is not required to activate or solubilize protein, which then supports the immobilization of added water, as no water is added during manufacture. Activation of protein in spreadable sausages is not desired in any case as activated protein increases firmness of a product and reduces spreadability. Nitrite (see Chapter 7, Section 7.2) is added because of its contribution to the development of curing colour and flavour and because of its role as a hurdle against spoilage. *Salmonella* spp. are a common problem in raw spreadable sausage and levels of around 125 ppm of nitrite, in combination with around 25 g of salt per kilogram of product, create an effective hurdle against this microorganism. Different countries permit different levels of nitrite in the finished product. Nitrite should be added up to the maximum permitted level as it is an important hurdle against microbiology spoilage in raw fermented spreadable sausages.

Nitrate is generally not added as there is insufficient time for it to be reduced to nitrite in order to contribute to the development of curing colour or to inhibit bacterial growth. The level of nitrite added to raw fermented spreadable sausage, finely cut or coarse minced, has to be adjusted carefully and much less nitrite is used in raw fermented spreadable sausages than, for example, in sliceable salami, which experiences a long drying period in which nitrite is broken down. Raw fermented spreadable sausages are also not heat treated and therefore no nitrite is lost as a result of heat treatment, as it is, for example, in the production of cooked sausages or cooked hams. In addition, raw fermented sausages are commonly filled into waterproof casings and therefore significantly more nitrite remains within the product than would be the case if another kind of casing were used. Waterproof casings are an effective barrier against oxygen ( $O_2$ ) and oxidation of nitrite to nitrate is therefore slowed down.

Ascorbate or ascorbic acid (see Chapter 7, Section 7.4) are also added to raw spreadable sausages. They act as colour enhancers and to a small degree also as antioxidants. The level of ascorbate added is around 0.6–0.7 g per kilogram of sausage mass whereas ascorbic acid is applied at 0.4–0.6 g per kilogram of sausage mass. Care has to be taken during processing that ascorbic acid does not come into direct contact with nitrite. These materials react instantly with each other, forming nitric oxide (NO) gas; firstly, NO is a toxic gas and, secondly, the amount of nitrite lost as a result of such a

reaction is not available any longer for the formation of nitrosomyoglobin. Ascorbic acid is predominantly added to fully acidified products made on an industrial scale, which reach a final pH of around 4.9–5.0. The addition of ascorbic acid speeds up the development of curing colour during the decline in pH in the product during fermentation.

Protective cultures are occasionally added to support the development of curing colour and flavour. Members of the genera *Micrococcus* and coagulase-negative *Staphylococcus* are used. These bacteria also suppress the growth of naturally present spoilage bacteria such as *Pseudomonas* spp. and are of great help if microbiologically questionable material is processed (although ideally this should not be the case in the first place). Most of these protective cultures also support natural acidification to a small degree, by helping to convert glucose primarily into lactic acid and also into other organic acids. As a result, the pH decrease by around 0.2–0.3 units to a level of around pH 5.4–5.5. Around 2–3 g of dextrose or 3 g of GDL are also occasionally added per kilogram of sausage mass to aid this natural acidification process. A pH below 5.5 is an effective hurdle against Enterobacteriaceae and also inhibits growth of bacteria such as *Salmonella* spp.

Starter cultures are occasionally added to products that should have a final pH of 5.3–5.4 and are very often added to products which should have a final pH of 4.9–5. Lactic acid bacteria such as *Lactobacillus* spp. and *Pediococcus* spp. are commonly introduced and numbers around  $10^7$ – $10^8$  per gram of sausage are present after fermentation for 24–48 h. The addition of 6–7 g of dextrose, or a combination of 5 g of dextrose and 3 g of lactose in conjunction with acidifying starter cultures is generally effective in lowering the pH value to around 4.9–5.0. In industrial production of raw spreadable sausages, GDL (see Chapter 6, Section 6.15) is commonly added at levels of 6–7 g per kilogram of sausage mass to achieve fast acidification to a pH of around 4.9–5.0. The hurdle against microbiological spoilage created by the addition of GDL and fast acidification is not as effective, however, as the hurdle created by acidification induced by starter cultures in combination with sugars even if the same final pH is obtained. GDL can also cause a slightly bitter–sour taste in the product. As a compromise, a combination of starter cultures, sugars and GDL is frequently applied to products that are intended to be fully acidified.

In finely cut products, because of the fat's large surface area, colours such as fermented rice, allura red or carmine (see Chapter 6, Section 6.13) are occasionally added to create a stronger red colour. The large surface area of the fat makes the red curing colour from the meat less intense and the product can be pale despite containing the correct level of nitrite and colour enhancer.

Spices and herbs are added to taste. Care has to be taken that natural spices, which frequently have a high bacteria count, are not added in large amounts as microbiological spoilage could be the result. Smoke flavour is occasionally added to products filled into waterproof casings as these products

are never smoked. Fresh onion is commonly added to coarse ground raw spreadable sausage. *Salmonella* spp. are often found in fresh onions, however, and this can be a problem as, according to most food standards, *Salmonella* spp. must be negative in 25 g of the finished meat product.

Hydrocolloids such as xanthan or guar gum (see Chapter 5, Section 5.3.1 and 5.3.2) are commonly applied at levels of 2–4 g per kilogram of sausage to increase spreadability. They are particularly frequently added to coarse-minced products as these products are less spreadable than finely cut products. This is because the fat in the coarse-minced sausage has a much smaller surface area than the fat in a finely cut sausage. The addition of low-bloom gelatin, such as 60 bloom, does not improve spreadability, however, and should therefore be avoided.

Sugars such as dextrose, lactose and maltodextrin with a DE value around 30 are commonly introduced into raw spreadable fermented sausages as food for starter cultures. The sugars also contribute to flavour and cover up high levels of salt in the product. Flavour enhancers such as MSG or ribonucleotide (see Chapter 6, Section 6.5 and 6.6) are commonly added as well.

### 21.3 Manufacturing technology

As mentioned earlier, a clear distinction has to be made between products manufactured on a small scale and sold on site (i.e. in a butcher's shop) and products manufactured on a large scale and sold in supermarkets. It can be up to 2 weeks before products made for supermarkets are sold and consumed, whereas products manufactured by a butcher are generally sold and consumed within several days. The short period of time between production and consumption of products made on a small scale means that they are safe even if they are not acidified. Sausages made in this way are stored chilled at temperatures below 4 °C all the time and the combination of the various hurdles in place (the low bacteria count of the meat and fat materials used, the presence of nitrite, the chilled storage and the very short period of time between manufacture and consumption) results in a non-acidified, but nevertheless safe final product. The pH value of non-acidified raw sausages is generally around 5.5–5.6.

Other products are semi-acidified to pH values between 5.3 and 5.4. In case recipes for this type of sausage contain higher levels of lean meat and therefore less fat, less sugar needs to be added. If too much sugar is added, the pH will drop below 5.3 as increased levels of meat result in stronger acidification owing to the increased level of glucose (glycogen) originating from the meat itself.

Industrially produced raw spreadable sausage commonly has a shelf life of several weeks and acidification is the usual method employed to ensure that it remains safe. The pH value of industrially produced products (also

called fully acidified products) is between 4.9 and 5.0. At this pH, bacteria such as *Staphylococcus aureus* or *Salmonella* spp. are inactivated and the products can even be stored at room temperature. However, in order to introduce an additional hurdle these products are generally stored chilled at a temperature below 4 °C.

### 21.3.1 Finely cut spreadable raw sausage

A finely cut spreadable raw sausage must not contain visible meat and fat particles and must have excellent spreadability. The raw meat and fat material to be processed either can be processed semifrozen or is minced with a fine blade, such as a 2–3 mm blade, and then placed in the freezer overnight. Semifrozen material is preferred in larger-scale production, however, as no thawing loss occurs and the additional processing step of mincing and freezing is not required. Recipes for finely cut products commonly contain around 35–50% fat. The semifrozen, or minced and semifrozen, material is placed in the bowl cutter and all additives except salt and nitrite are added evenly while the meat and fat are cut at a medium–fast knife speed. If ascorbate is applied as a colour enhancer at the beginning of the cutting process, nitrite can also be added at the same stage. As the curing colour must develop quickly, ascorbic acid (rather than ascorbate) is commonly applied as colour enhancer though. If this is the case, then nitrite is added at the end of the cutting process whilst ascorbic acid is added at the beginning to avoid direct contact between them. All the materials are then cut at a high knife speed until the temperature is around 12–14 °C. Salt and nitrite are then evenly added and cutting continues to a temperature of 16–18 °C. Salt is added to the sausage mass at the end of the process because activation of protein by salt is not desired; this would increase firmness and reduce spreadability of the sausage. At temperatures of around 12–14 °C the finely cut fat covers meat particles, and very little protein is activated if salt is subsequently added. The small amount of protein activated by the addition of salt transforms into a gel when the product is acidified to pH levels between 4.9 and 5.0, but this gel breaks easily and the product is spreadable. Contradictory opinions do exist, nevertheless, about the point when salt should be added to the sausage. Some experts say that salt can be added at any time during the process as long as neither water nor phosphates are introduced into the sausage mass. Since phosphates and water are not added, these experts believe that the degree of swelling of proteins will be always the same, regardless of the point at which salt was introduced. However, the early addition of salt causes the formation of some sol but in products which are not or only partially acidified the presence of a sol is not negative as the pH value does not drop below 5.3. At a pH value of 5.3 and above, a sol obtained as a result of early addition of salt would never be transferred into a gel via acidification, therefore not affecting spreadability in a negative way. Most manufacturers add salt at the later production stage based on the understanding that salt is

primarily introduced for taste and flavour and not for activating protein. A few follow established procedures and add salt at an earlier stage.

In general, spreadability can be increased in a finely cut spreadable raw sausage by adding more fat and/or by increasing the surface area of the fat by cutting it for longer. The addition of oil and/or xanthan or guar gum also increases spreadability but these ingredients are more frequently added to minced spreadable raw sausages as the fat surface in a minced product is significantly less than that of a finely cut product. A finely cut spreadable raw sausage is essentially a meat-in-fat emulsion and the layer of fat present in the outer phase covers the meat particles, making the product spreadable.

Another way of obtaining and maintaining spreadability is to denature proteins in the raw ingredients before the sausage is produced. If this is the case, the manufacturing process is as follows. The lean meat portion of the recipe (and maybe the fatty trimmings as well) is minced with the 4–6 mm blade and nitrite is added at the correct levels to obtain a strong curing colour. Salt is occasionally added as well but it is not necessary as the main purpose of adding nitrite is to ensure formation of nitrosomyoglobin. Development of curing colour takes place overnight and the following day organic acids such as lactic acid or GDL can be added to the cured material to lower the pH value to around 5.0–5.1. During acidification, proteins are denatured, losing their functionality. If the cured and denatured meat is finely cut, no sol forms even if salt is added because proteins are no longer functional.

Care has to be taken that the development of the red curing colour via the addition of nitrite is completed before the proteins are denatured as denatured myoglobin would not turn into nitrosomyoglobin. Nitrite, organic acids, ascorbic acid and GDL must not be added at the same time as this would cause the proteins, including myoglobin, to be denatured before the desired red curing colour is obtained. Hence, nitrite must not come into direct contact with any materials applied as colour enhancers (see Chapter 7, Section 7.4). A premix consisting of spices, ascorbic acid, nitrite and salt should not be used either for the same reason, as nitrite reacts with ascorbic acid if present at the same time. During the precuring of the meat or fatty materials, nitrite and salt are usually added on their own and colour enhancers are introduced into the sausage mass during the manufacture of the product itself.

Finely cut spreadable raw sausage can also be produced using an emulsifier. When an emulsifier is used, all the (mostly slightly frozen) meat and fat materials and all the additives except salt and nitrite are cut in the bowl cutter until a temperature of around 10–12 °C is reached. Salt and nitrite are added evenly to the mass, and the sausage mass is passed through the emulsifier so that a fine and creamy mass is obtained. The final temperature is between 16 and 18 °C. Alternatively all the slightly frozen meat and fat materials can be minced with the 8–13 mm blade. They are then placed into the bowl cutter or any other mixing device and all additives, including salt and nitrite, are added to the mass during mixing. Mixing takes place until all the additives

are evenly distributed and then the sausage mass is passed through the emulsifier. Occasionally, the mass is passed through the emulsifier twice. The final temperature is again around 16–18 °C. Because salt is introduced quite early on in this process, before the fat has covered the meat, the finished product is slightly firmer.

Once a fine and creamy product is obtained, the sausage mass is commonly filled under a vacuum into the desired casings. Quite commonly, waterproof casings such as monolayer plastic casings are chosen but water-permeable casings made from cellulose or small-diameter fibrous casings (see Chapter 35, Sections 35.2 and 35.5) are also used. Portions are usually between 100 and 300 g and the diameter of the casings used varies commonly between 40 and 50 mm.

### **21.3.2 Coarse-minced mixed spreadable raw sausage**

Coarse-minced–mixed spreadable raw sausage is generally produced from fatty meat trimmings, and these are cut for a short while in the bowl cutter. As always in the manufacture of meat products, the meat and fat materials must have low bacteria counts. A low bacteria count is especially vital in this case as raw products are going to be produced. The fat material processed must not be rancid. In general, the same additives are introduced as in the manufacture of finely cut spreadable raw sausage. In coarse-minced products, if the fat level is reduced below 25%, the final product is not sufficiently spreadable.

Commonly, slightly frozen material is processed as it can be cleanly cut during mincing. Most commonly all additives are added evenly into the bowl cutter whilst the meat and fat materials are cut at a slow knife speed for a few turns. The temperature of the mass at this point is between –2 and 4 °C. The coarsely cut sausage mass is then minced with the desired blade, usually between 3 and 6 mm. Smearing of fat has to be avoided during mincing as clearly cut meat and fat particles should be visible in the finished product. All mincer blades and knives utilized must also be free of rust or any other foreign bodies to avoid contamination. Mincing can take place in two ways. Either small pieces of meat and fat material from the bowl cutter are minced with a single blade, or a double set of knives is used to cut larger pieces of meat and fat into small particles. When a double set of knives is used, fist-size pieces of meat and fat material were initially mixed in a mixer, and all additives were then evenly introduced. After thorough mixing, the sausage mass is passed through the mincer in which it is first minced with a 13–20 mm blade and then minced for a second time with the blade that will give the desired particle size. Both mincing processes take place in sequence and no double handling is required. Once mincing is completed, the mass is frequently mixed for a short while before being filled into plastic, fibrous or cellulose casings of 40–60 mm diameter.

Another possible method (which is not frequently followed, however) is

to mince all meat and fat materials with the desired blade and then to mix the minced materials whilst all additives are introduced. Introducing additives to the meat and fat material before mincing distributes the additives better than if they are added to the minced meat materials. Uneven distribution of additives such as salt and especially nitrite within the sausage mass can result in unstable products from a microbiological point of view. Unevenly distributed acidification materials such as GDL can also lead to insufficient acidification in sausage, thus creating a potential risk for food poisoning.

The addition of cold-swelling gums such as guar or xanthan gum significantly improves and helps to maintain spreadability in coarse spreadable raw sausage. The addition of oil also increases spreadability and around 5% added oil can improve spreadability significantly.

As described under finely cut products, the protein in the meat materials can be denatured prior to processing in order to avoid activation of protein during mincing and therefore to improve spreadability. Before protein is denatured by the addition of organic acids or GDL, the red curing colour has to be fully developed (see Section 21.3.1).

After proper mixing, the coarse sausage mass is filled predominantly into waterproof casings. Casings permeable to air made from cellulose are occasionally used instead. Whatever type of casing is used, smearing should be avoided during the filling process.

### **21.3.3 Fermentation**

The fermentation process differs according to the degree to which the sausage acidifies during manufacturing. Whether the sausage is finely cut or coarsely minced is of no consequence in the fermentation process.

#### *Non-acidified products*

The pH value of non-acidified products hardly drops during manufacture and is finally around 5.5–5.6. This kind of product is chiefly filled into small-diameter natural casings and left hanging at room temperature (around 20 °C) for 12–24 h. During this time, curing colour develops through the impact of nitrite. A small number of non-acidified products are filled into small-diameter (around 40 mm) cellulose casings. These products are then cold smoked at 20–25 °C several times until the desired smoke colour or intensity of smoke flavour is obtained. Generally, cold smoke is applied to all raw fermented spreadable sausages once curing colour has fully developed. Otherwise substances within smoke, such as phenols, formaldehyde and other acids can interfere badly with the development of curing colour. Products smoked in a very early stage of fermentation would also be a grey colour on the outside. The smoked products are then refrigerated at temperatures below 4 °C. The loss in weight during manufacture is between 4 and 7%.

As already mentioned, the safety of this type of product relies primarily on the short time between manufacture and consumption which is generally

between 2 and 4 days. Other hurdles against spoilage are the low bacteria count of the raw materials, the presence of salt at 24–26 g per kilogram of product and the presence of nitrite at maximum permitted levels. Safety is also positively affected by the application of smoke. The high level of fat within the product in conjunction with some loss in weight during smoking and drying generally reduces the  $A_w$  to levels at 0.95. Therefore an additional hurdle against Enterobacteriaceae is in place although  $A_w$  is not the main hurdle against microbial spoilage in this type of product. Places where food is sold on a large scale such as in supermarkets generally do not accept this type of product as they are not produced with an adequate quality control system in place.

### *Semi-acidified products*

Semi-acidified products contain a small amount of added sugars as well as starter cultures, or GDL. The pH of these products drops to around 5.3–5.4 during fermentation, creating a hurdle against growth of *Salmonella* spp. Nitrite is also a stronger hurdle against microbiological growth at reduced pH levels. The spreadability of the sausage remains excellent, however, because the pH never reaches 5.2 and the sol obtained by the impact of salt is not denatured. Sugars such as dextrose or GDL are added at around 3–4 g per kilogram of product to cause a decrease in pH of 0.3–0.4 units. Semi-acidified products are exposed to temperatures of around 18–22 °C for 2–3 days at an RH of between 85% and 90% and conditions of slow air speed for curing colour to develop fully and the pH to drop to the desired level. Temperatures above 24 °C are not recommended as nitrite then ceases to be an effective hurdle against microbiological growth. There is then a microbiological risk as there are no other hurdles, such as pH or  $A_w$  value in place during the first 2–3 days of fermentation. The reduction in pH value speeds up the development of curing colour as a larger amount of undissociated nitrous acid is produced at lower pH levels, resulting in larger quantities of NO, which supports the formation of a strong curing colour.

When manufacturing semi-acidified products with the help of starter cultures and sugar, the temperature can be reduced to 12–14 °C once a pH value 5.3–5.4 is obtained; spreadability would be badly affected were the pH to drop below 5.3. Reducing the temperature to around 10 °C stops the lactic acid bacteria from fermenting residual sugars into acid and therefore the pH remains stable. The remaining sugars within the product then contribute to flavour development. When acidification is brought about only by the addition of GDL, acidification cannot be halted. The chemical process in which GDL turns into gluconic acid in the presence of water does not stop when the temperature is reduced. A problem in the manufacture of semi-acidified products can be that the entire sausage turns grey in colour after a few days when previously it was a strong red colour. At pH values of around 5.3–5.4, nitrosomyoglobin is not completely denatured. This non-stabilized nitrosomyoglobin turns in time into metmyoglobin, which is grey as nitric

oxide breaks away from myoglobin after a while under the impact of O<sub>2</sub> and/or light (photolysis), thus enabling myoglobin to be oxidized to metmyoglobin. This problem is more prevalent in products with low fat levels as higher levels of meat, and therefore myoglobin, are present in the product. The increased level of myoglobin results initially in a higher level of nitrosomyoglobin, which is not denatured and subsequently a larger quantity of metmyoglobin forms. The only strategies to avoid the formation of a grey colour are to add the maximum level permitted of nitrite, as well as sufficient colour enhancer, and to store the product away from direct light. The addition of colours such as carmine or fermented rice can also mask the unwanted grey colour.

Semi-acidified products are generally filled into cellulose casings with a diameter of around 40–45 mm. A small quantity of these products, however, are filled into waterproof casings of the same diameter. Once curing colour is fully developed and the pH has dropped to around 5.3–5.4, cold smoke at 20–25°C is applied to product in cellulose casings. This takes place at an RH of 80–85% and temperatures between 18 and 20 °C, lasting for around 30–45 min. The process is repeated several times over the next 6–24 h to obtain the desired smoke colour. Excess application of smoke can reduce spreadability of the product, especially on the outer layers, as smoking has a fairly strong drying effect. The formaldehyde present in the smoke also reacts with protein in the sausage, thus creating a hard rind around the product, very similar that found after case hardening in sliceable salami. Products filled into water-permeable cellulose casings are subsequently dried at a temperature of 14–16 °C, an RH of 74–78% and under a slow air speed for a few days. A loss in weight of around 10–12% is seen. Smoke flavouring is commonly added directly to products which will be filled into waterproof casings as these products are not smoked at all. If a product is filled into a waterproof casing, the process of drying is also obsolete as no moisture can be removed and no loss in weight takes place.

To produce safe semi-acidified products, materials with a low initial bacteria count must be used, and maximum levels of salt and nitrite must be added. The product may also be smoked. The drop in pH value below 5.5 then ensures that the product is safe. If the product is dried, the  $A_w$  is often reduced to, or even slightly below, 0.95, which is another hurdle against Enterobacteriaceae.

#### *Fully acidified products*

The pH of fully acidified products is reduced to levels between 4.9 and 5.0. This is usually due to the impact of sugars in conjunction with starter cultures, or to the impact of GDL alone. A combination of sugars and starter cultures as well as GDL is occasionally applied. The introduction of 7–8 g of dextrose or GDL, or a combination of 5 g of dextrose with 3 g of GDL per kilogram of sausage mass usually leads to a decrease in pH value to around 4.9–5.0. The vast majority of raw spreadable sausages nowadays, finely cut or coarse

minced, sold on a large scale are fully acidified products as food safety is of utmost concern.

Waterproof and also sometimes cellulose casings with a diameter of 40–45 mm are commonly used. Waterproof casings are usually the first choice as no loss in weight during manufacture is usually desired. The filled sausage is treated more or less in the same way as a semi-acidified sausage. It is exposed to temperatures of 20–24 °C, an RH of 85–90% and conditions of low air speed for around 2–3 days. During this period, the pH value drops to a level between 4.9 and 5.0, depending on the type and amount of acidification additive added in the first place, and curing colour develops. Once the low pH is obtained, the product is safe from a microbiological point of view and the curing colour is fully stabilized. This is in contrast with semi-acidified products, in which nitrosomyoglobin is not completely denatured and therefore the myoglobin is in danger of being oxidized. As is the case in the manufacture of semi-acidified products, temperatures above 24 °C are not recommended as nitrite ceases to be an effective hurdle against microbiological growth and no other hurdle is in place during the first 2–3 days of fermentation.

Cold smoking and drying of products filled in cellulose casings, and treatment of non-smoked products filled in waterproof casings, take place in the same way as in the manufacture of semi-acidified products.

A fast and steep decrease in the pH to levels around 4.6 during fermentation at temperatures above 26 °C, as a result of elevated levels of sugars or GDL, can cause pores to form within the sausage mass and gassing to occur. The product, especially if finely cut and filled into waterproof casing, can balloon. The carbon dioxide (CO<sub>2</sub>) produced by heterofermentative *Lactobacillus* spp. is largely responsible for this gassing. Acidification therefore should not take place too fast as heterofermentative *Lactobacillus* spp. are more active during a fast decrease in pH. The capillaries of muscle tissue in raw spreadable sausages filled into permeable casings are blocked owing to the presence of finely cut fat, which contributes to this problem. In extreme instances, the casing bursts. The pH of products produced on a large scale should be below 5.2 at the point of consumption in order to guarantee product safety. Spreadable raw sausage filled into a waterproof casing generally has an  $A_w$  of 0.96–0.97 and is therefore not stabilized against microbial spoilage by its  $A_w$  value. On the other hand, products filled into cellulose or other non-waterproof casings and dried for several days after being smoked have an  $A_w$  of around 0.95, which is a hurdle against Enterobacteriaceae.

#### 21.3.4 Microbiology

*Salmonella* spp. are the greatest risk in spreadable raw sausage and, at numbers above 10<sup>5</sup>–10<sup>6</sup> per gram of product it causes illness. Some food standards have very strict rules in place regarding the presence of these bacteria in raw spreadable sausage and demand that it is negative in 25 g. The addition of around 2.5% salt, the presence of nitrite and pH levels below 5.5 inhibit

growth of *Salmonella* spp., however, in this product. In spreadable raw sausage with a fat content above 40%, the  $A_w$  right from the beginning is around 0.96 and therefore  $A_w$  is a partial hurdle against microbiological growth (fat contains only around 10% moisture compared with 70–75% within muscle tissue). If the product is dried for a few days, the  $A_w$  decreases further, making  $A_w$  a more effective hurdle. Products filled into non-waterproof casings are generally dried for longer periods and therefore their  $A_w$  is reduced to, or below, 0.95. Only at this level does  $A_w$  become an effective hurdle against *Salmonella* spp. Storage of the product at temperatures below 4 °C is another effective hurdle against growth of the bacteria.

In spreadable raw sausage, the presence of bacteria such as *Campylobacter jejuni*, *Yersinia enterocolitica*, *Listeria monocytogenes* and enterohaemorrhagic strains of *Escherichia coli* (EHEC O157:H7) can be a microbiological risk. EHEC causes illness at low counts of 50–100 per gram of product. *C. jejuni* grows slowly below 28 °C but low counts of around 100 per gram of product are sufficient to cause illness. *Y. enterocolitica* presents a risk at counts around and above  $10^2$ – $10^3$  per gram of sausage, and counts of *L. monocytogenes* above  $10^2$  per gram of product can cause illness as well. Counts of *L. monocytogenes* below  $10^2$  of product generally do not cause illness but most food standards in the world have strict regulations in place stipulating that *L. monocytogenes* has to be negative in 25 g. As in the manufacture of fermented salami, acidification of products below a pH value of 5.0 reduces the number of bacteria such as *L. monocytogenes*, *E. coli* (O157:H7) and *Salmonella* spp. because those bacteria cannot compete with the lactic acid bacteria.

### 21.3.5 Packing and storage

Products produced on a small scale, which do not acidify, are usually not packed and are sold unpackaged in pieces to the consumer. They are stored at temperatures below 4 °C for a very limited time (2 days maximum) before being consumed.

Products which are semi-acidified to a pH value of 5.3–5.4 and fully acidified products with a pH of around 4.9–5.0, are commonly modified atmosphere packed. The gas mix within the packaging is usually 30% CO<sub>2</sub> and 70% nitrogen (N<sub>2</sub>).

Products filled into waterproof casings are commonly not packaged further. The casing itself forms the final packaging and all the necessary information such as the list of ingredients, nutritional value, name and code of the product is displayed on the casing itself.

Occasionally, products in waterproof casings (semi-acidified or fully acidified) are packed in secondary packaging such as modified-atmosphere packaging. The secondary packaging, however, can also simply be a sealed plastic cover that does not contain any CO<sub>2</sub> or N<sub>2</sub>.

Products filled into permeable casings made from cellulose, semi-acidified or fully acidified, are most commonly modified atmosphere packed. The gas

mix in the packaging is usually 30% CO<sub>2</sub> and 70% N<sub>2</sub>. Elevated levels of CO<sub>2</sub> would increase shelf life but can have a negative impact on taste as carbonic acid is produced from the reaction between CO<sub>2</sub> and water (CO<sub>2</sub> + H<sub>2</sub>O → H<sub>2</sub>CO<sub>3</sub>), which can make the product slightly sour.

The shelf life of acidified products, with a pH of around 4.9–5.0, packed under a modified atmosphere and stored at temperatures below 4 °C, can be 30–35 days. Even though growth of *Salmonella* spp. is inhibited in all semi-acidified and fully acidified products (pH below 5.5) filled into waterproof or permeable casings, they are most commonly stored refrigerated at temperatures below 4 °C so that there is an additional hurdle in place against microbiological growth. A pH below 5.2 also inhibits formation of toxin from *Staph. aureus*. Fully acidified products with a pH below 5.2 and filled into permeable casings are also sometimes dried slightly and therefore have an  $A_w$  of or below 0.95. These products are occasionally stored at room temperature as growth of *Salmonella* spp. is inhibited at low pH and low  $A_w$ . Even these doubly safe products, however, are frequently stored at temperatures below 4 °C.

## 21.4 Summary of critical production issues

- 1 Meat and fat material to be used should have a low bacteria count and values between 10<sup>2</sup> and 10<sup>3</sup> per gram of material are optimal.
- 2 The pH value of meat should be below 5.8.
- 3 The level of fat should be above 25% for good spreadability.
- 4 High levels of hygiene should be maintained during processing to ensure that microbial contamination does not take place.
- 5 Salt at around 25 g per kilogram of product and the maximum permitted level of nitrite should be added.
- 6 Sugar (in conjunction with starter cultures) or GDL should be added at a level appropriate for the desired pH of the finished product (either semi-acidified to a pH value of 5.3–5.4 or fully acidified to pH levels between 4.9 and 5.0); an  $A_w$  at or below 0.95 as a result of drying is an additional hurdle against Enterobacteriaceae.
- 7 The fermentation temperature should not be above 24 °C.
- 8 Cold smoke should be applied once curing colour is fully developed in products filled into permeable casing.
- 9 Most products are modified atmosphere packed with the gas mix containing around 30% CO<sub>2</sub> and 70% N<sub>2</sub>.
- 10 Most products are stored at temperatures below 4 °C. Fully acidified products can be stored at room temperature.

## 22

# Typical raw fermented sausage products from around the world

### 22.1 Teewurst (finely cut tea sausage) (Austria and Germany)

A typical recipe for high-quality teewurst contains around 10–15% (95% CL-grade) beef, 50–55% (95% CL-grade) lean pork and around 30–35% pork back fat. Variations in the ratio of meat to fat are possible if certain other materials are used. If fatty pork belly is chosen as a raw material, for example, the amount of lean pork is reduced as there is already some lean muscle present in the fatty pork belly.

Additives used in the manufacture of teewurst are salt, at a level of 25 g per kilogram of product and nitrite, at the maximum legal level. A colour enhancer can also be used, most commonly ascorbic acid at a level of 0.5 g per kilogram of product. The spices chosen are white pepper, paprika, cardamom and ginger, and a touch of rum is added as well. Starter cultures are used and sugar is added at around 3–4 g per kilogram of sausage mass so that the product acidifies to a pH of around 5.3. Occasionally, acidification to a pH of around 5.3 is brought about instead by the addition of around 3–4 g of GDL per kilogram of sausage mass.

The chilled materials can be minced with the 3–4 mm blade and subsequently frozen before being processed. Alternatively, if a high-speed bowl cutter with sharp cutter knives is available, the materials can be processed semifrozen without being minced previously. All the meat and fat materials, whether preminced or not, are placed in the bowl cutter and all additives except salt and nitrite are added. The sausage mass is cut at a high speed until the temperature reaches around 12–14 °C. Salt and nitrite are added at this stage. Cutting continues until temperatures of around 16–18 °C are obtained. The

sausage mass is then filled into small-diameter (45–50 mm) cellulose casings and fermented at 18–22 °C for around 2–3 days. During this time, curing colour develops and the pH is reduced to the desired level. Cold smoke is applied after around 36–48 h and the level of smoking can vary greatly. Generally, however, teewurst is only slightly smoked. The smoked product is then dried for several days at 14–16 °C and an RH of around 75–78% until around 10% in weight is lost. The finished product is commonly modified atmosphere packed and stored at temperatures below 4 °C.

The manufacturing process can vary. Finely cut teewurst is frequently filled into non-permeable casings instead of cellulose casings. Higher levels of sugars and/or GDL can also be added during the manufacturing process and therefore the pH drops further, to about 4.9–5, making the sausage stable against microbial spoilage (the combination of acids obtained from fermented sugars and acidification due to GDL is more effective against bacteria such as *Salmonella* spp. than the acidification due to GDL alone). Products filled into non-permeable casings are not smoked and instead a small amount of smoke flavouring is added. They are exposed to temperatures between 20 and 24 °C for 36–48 h after being filled to allow curing colour to develop and the pH to drop to around 4.9–5.0. The fully acidified product is then modified atmosphere packed, but it is also generally stored chilled. Most sausages made in this way are not packed further and the non-permeable casing serves as the final packaging.

## 22.2 Coarse onion mettwurst (Austria and Germany)

Coarse onion mettwurst is generally made from 60–65% Cl-grade fatty pork trimmings. Fatty pork bellies are commonly used as well and are quite often the only source of meat and fat material. Well-chilled material at a temperature of between –2 and 2 °C is placed in the bowl cutter and cut at a slow knife speed whilst all additives, including salt and nitrite, are evenly introduced. If the sausage is required to acidify during subsequent fermentation, starter cultures and sugars, as well as GDL, are added at this stage as well. Peeled onions are also introduced at this stage at levels of around 3–5%. The evenly mixed and coarsely cut mass is then minced with the 4–6 mm blade. Smearing should be avoided during mincing as a clean cut is desired. The minced mass is filled into either cellulose or waterproof casings. It is subsequently treated during fermentation as described in Section 22.1. As onions frequently contain *Salmonella* spp., onion mettwurst is often acidified to a pH value between 4.9 and 5.0 to establish a strong hurdle against bacterial growth. Browning can be a problem in onion mettwurst as onions contain high levels of pyruvic acid. The pyruvic acid interferes with the reaction between nitric oxide and myoglobin in which nitrosomyoglobin usually forms and is also a strong oxidizing agent. To overcome this problem, reduced levels of onion can be

introduced. It is also advantageous to choose less pungent types of onions; pyruvic acid is chiefly responsible for pungency, and so less pungent onions will contain lower levels of pyruvic acid. Alternatively, partially cooked onions or onion powder can replace the fresh onions.

## 23

# Cured air-dried meat products

If a few important rules are followed during production, cured air-dried meat products are generally very stable and robust as well as being safe and great-tasting products which can be produced without major difficulty. Drying of meat as a means of preservation was discovered many thousands of years ago and this basic principle has not changed up to the current day. Very different dried meat products are produced worldwide but there are some facts in common in the production of all these products. To ensure that safe products are made, meat with a low bacteria count should be used and salt as well as other  $A_w$ -reducing additives should be present at a high level as acidification as a means of preservation never arises as it does, for example, in the manufacture of fermented salami. The presence of nitrite is also another important hurdle. As within the production of salami, 'experience' is a highly desired additive especially for the salting process and 'time' is another important factor. Drying, in conjunction with the development of curing colour and flavour of the product, can only be speeded up to a certain extent but is vital for a good quality product. Air-dried products are generally made from pork and beef as well as buffalo and deer but the same principles apply to products such as dried game and fish. Air-dried cured products are commonly consumed in a cold state and thinly sliced. Finished products generally exhibit a high level of salt; around 4.5% or higher is commonly seen.

### 23.1 Selection and preparation of raw materials

As air-dried products are never heat treated, the microbiological status of the meat material to be processed is of vital importance. Contamination of meat

should be avoided at any stage and as early as during the slaughtering and scalding of pigs. Scalding in a bath of hot water contaminates meat to a much greater extent than scalding whilst hanging; during scalding in a bath, some scalding water always enters the internal areas of the pig whereas such contamination is largely avoided by scalding of pigs with the carcass hanging. Pigs should also only be slaughtered around 6 h after being fed as digestion of food leads to increased bacteria activity within the intestines therefore increasing the risk of migration of bacteria into surrounding muscle tissue. In addition, pigs should not be treated badly with prodders prior to slaughter as the resulting acute stress, as well as resulting in PSE meat, causes bacteria present in the intestines to pass through the gut wall and to contaminate normally clean areas of muscle tissue as well. After slaughter, the pig carcass has to be cooled rapidly, once again, to control bacterial growth and, by doing so, the amount of PSE pork (see Chapter 4, Section 4.1) is reduced at the same time. Despite fast cooling of the pig carcass, cold shortening (see Chapter 4, Section 4.5) has to be avoided at the same time. A temperature in meat below 4 °C reduces the risk that *Salmonella* spp. and *Staphylococcus aureus* can grow and 4 °C should be obtained within 14–18 h after slaughter in pork. Maintaining a temperature below 4 °C during boning and the first stage of salting is the first and also very important hurdle against microbiological growth in the production of cured air-dried products.

Processing PSE-character pork actually improves the diffusion of salt into inner areas of muscle tissue as the open-fibre structure enables salt to diffuse at a faster rate into muscle meat, thus lowering the  $A_w$  earlier in the core. The pale colour of PSE pork, however, leads to pale-coloured finished products, which is not preferred. DFD meat (see Chapter 4, Section 4.1), predominantly seen in beef but to a small degree also in pork, has to be avoided when in the manufacture of air-dried products as rigor mortis has taken place only partially in DFD meat, resulting in insufficient acidification of muscle tissue. Insufficient acidification gives enzymes a perfect breeding and working environment and the risk of microbiological spoilage is greatly enhanced. DFD meat also exhibits a closed-fibre structure and diffusion of salt into inner areas of meat is drastically slowed down, meaning that microbiological stability of the salted product is obtained much later in the production process. DFD meat also demonstrates less meat taste since inosine is present at very low levels. In addition, the formation of curing colour within DFD meat is badly affected as the high pH value seen in such meat means that low levels of undissociated nitrous acid are obtained, thus reducing the amount of nitric oxide (NO) obtained (see Chapter 7, Section 7.3). Finally, the speed of drying is reduced in products made from DFD meat as the high pH value of the meat itself correlates with a high WHC.

The bacteria count of meat to be processed for air-dried meat products should be between  $10^2$  and  $10^3$  per gram of product or per square centimetre of surface and the pH value should be between 5.5 and 5.8. Within such a pH range, microbiological growth is controlled and the WHC of meat itself is

reduced in comparison with that of meat demonstrating elevated pH levels of around 6.0 or even above. At lower pH values closer to the IEP, removal of water during salting, equalization of curing additives and drying are speeded up and the WHC is lower because of less unfolding of proteins at reduced pH values. From the point of view of drying as well as diffusion of salt into muscle tissues, it is advantageous to use frozen and thawed meat, as cell walls are destroyed or partly damaged during freezing owing to the formation of ice crystals (see Chapter 4, Section 4.7). As a result, diffusion of curing additives is speeded up and moisture can be removed more quickly as the binding forces within muscle tissue are weaker owing to damaged muscle cells. Water is lost during the thawing process itself, water which does not have to be removed subsequently during drying; losing weight, or moisture, during thawing is less expensive than removing water through drying.  $A_w$  as an effective hurdle can be achieved more quickly by utilizing thawed meat than by using fresh meat. Care has to be taken, however, that thawing occurs at a rate and under thermal circumstances where bacterial growth is limited and kept well under control, especially on the surface of meat to be defrosted. Frozen and thawed meat are not permitted to be used, nevertheless, for the production of Parma ham as well as other air-dried products manufactured in France and Spain.

Commonly, cuts of pork legs or entire pork legs are utilized for the production of air-dried hams and fat connected to meat is regularly left on cuts such as pork loin as well as pork leg. Fat must not be rancid as rancidity is greatly enhanced during the weeks or even months of drying. The type of feed given to the pig during its lifetime has a significant impact on the consistency of the fat as well as on its susceptibility towards rancidity. Oil-containing feed supports the growth of soft fatty tissue which exhibits higher levels of unsaturated fatty acids thus making fat more susceptible to oxidation and therefore to rancidity. Also, the fat of pig fed a diet high in unsaturated fatty acids seems to have a slightly yellow tinge which is not desirable as visible fat should be white in colour. Specifications about the meat material purchased for processing commonly stipulate a maximum peroxide level and, if this value is exceeded, the meat material will be rejected. Despite the fact that the peroxide value (see Chapter 1, Section 1.9) does not directly demonstrate the degree of oxidation within fat, it is used as an indicator because several months will pass before the product is finally sold and consumed. Therefore, having any slightly rancid fat within the raw materials at the start of production should be avoided. Fattier cuts of meat, such as pork neck or pork belly, exhibit enhanced levels of intramuscular fat, which slow down the diffusion of additives such as salt into muscle tissue. Fat contains around 10% connective tissue and connective tissue forms a barrier against the diffusion of salt into inner areas of meat.

Boning is a crucial step during the manufacture of a raw air-dried product. A high degree of care has to be taken to avoid cuts into muscle tissue because air circulation during drying as well as the ability to apply smoke in the cuts

are badly affected. As a result, the  $A_w$  remains high in such areas, allowing mould to grow easily, which creates a microbiological risk through the formation of mycotoxins. Besides that, drying itself is also slowed down in those areas. Once deboned, layers of connective tissue such as epimysium covering individual muscles (see Chapter 1, Section 1.4) should be removed as penetration of curing additives, predominantly salt, is dramatically slowed down by the presence of connective tissue, which acts as a barrier.

## 23.2 Selection of additives

Only a few types of additive are used in the production of cured and air-dried products. Similar to the production of raw fermented salami, the aim is to remove moisture, and therefore water-binding additives such as carrageenan, protein and starch are not used. Salt is applied as a hurdle against microbiological spoilage; it reduces the  $A_w$  in freshly salted products as well as contributing to the flavour of the product. The level of salt added is commonly between 32 and 35 g per kilogram of untreated meat. After some loss in weight during salting and equalization of curing additives, an  $A_w$  of 0.95 (or below) is reached inside in the product, which makes the product microbiologically safe against Enterobacteriaceae. At an  $A_w$  of 0.95 the concentration of salt is around 4.3–4.5% within the product.

Nitrite (see Chapter 7, Section 7.2) is applied for the formation of curing colour, because of its contribution to curing flavour and especially as an additional hurdle against bacterial growth during the stage of salting and equalization of curing additives. Depending on the legal maximum limit of nitrite present in the finished product, between 250 and 700 ppm of nitrite are applied per kilogram of untreated meat. As within many other cured meat products, the level of nitrite permitted refers generally to nitrite present in the finished product and not to the level added during the manufacture of the product. Nitrate is still occasionally applied but only in products dried for a long period of time made in a very traditional way. Nitrate is not a hurdle against bacteria (i.e. is not bacteriostatic) and care has to be taken during the initial stages of the salting process when only nitrate is utilized. The addition of nitrate does not mean that nitrite is present as a hurdle; nitrate is only reduced to nitrite at temperatures above 8 °C by bacteria such as *Micrococcus* spp., and curing meat at such elevated temperatures would provide bacteria such as *Salmonella* spp. as well as *Staph. aureus* with a chance to grow. As an alternative, nitrite and nitrate are commonly applied together in order to have nitrite in place as a hurdle as well as nitrate for stabilization of the curing colour during prolonged periods of drying. For simplicity and safety, nitrite is most often the only material applied as it provides an instant hurdle against microbiological growth as well as directly contributing to the formation of curing colour.

Colour enhancers such as ascorbate or erythorbate (see Chapter 7, Section 7.4) are frequently added to stabilize the curing colour formed when residual nitrite is reduced directly to NO by the impact of ascorbic acid obtained from ascorbate, supporting the formation of nitrosomyoglobin. Generally, 0.6–1.0 g of ascorbate are added per kilogram of meat to be salted and reduction of nitrate, which is obtained as a result of oxidation from nitrite added in the first place, to nitrite in the later stages of drying is also accomplished in the presence of ascorbate. Ascorbic acid is not utilized as a colour enhancer as it would come into direct contact with nitrite on the surface of meat and the moisture present on the surface of meat is sufficient to trigger the reaction between nitrite and ascorbic acid, resulting in the production of highly toxic nitrogen oxides such as NO and nitrogen dioxide (NO<sub>2</sub>). Air-dried products are dried for weeks or months in any case before being sold and the development of curing colour does not have to take place at such a fast rate as within cured cooked sausages or even fast-fermented salami.

Whether to add sugars to cured air-dried products has long been a subject of debate as no, or insignificant, acidification takes place within the product. Slight acidification, however, does take place within meat when glucose is added at 2–3 g per kilogram of product because the naturally present *Lactobacillus* spp. ferment added sugar into lactic acid. The addition of sugar also adds to the flavour of the product as well as enhancing colour stability as sugar is food for bacteria, such as *Micrococcus* spp., which reduce nitrate to nitrite and therefore contribute to a stronger and longer-lasting red curing colour. However, during the initial stages of processing, the temperatures applied when curing with nitrite are below 5 °C and no reduction of nitrate to nitrite takes place as nitrate-reducing bacteria only work at temperatures above 8 °C. Lactose is known to complement the flavour of meat well and added sugars certainly reduce the level of saltiness within the product as the amount of salt added is high. The addition of sugar also causes a reduction in  $A_w$  as dissolved sugar ions immobilize water and therefore lower the amount of freely available water. The amount of sugar added varies greatly and is in most cases between 3 and 8 g per kilogram of meat. Excess levels of sugar would impart a sweet flavour to the product, which is generally not desired, except in some products made in Asia.

Spices and herbs are applied to taste and generally spices such as garlic, pepper and coriander are heavily used. In most cases, natural spices are chosen and oleoresins are only occasionally used. Protective cultures as opposed to starter cultures are occasionally applied to air-dried products for the purpose of enhancing and stabilizing curing colour as well as flavour within the product. These are not added for acidification purposes as is the case in the production of raw fermented salami. Cultures such as *Staph. carnosus* and *Lactobacillus pentosus* are commonly applied for colour and flavour development because these two species tolerate high levels of salt. Both bacteria contain the enzymes proteases, lipases as well as catalase. The presence of proteases and lipases favours good flavour development as proteins

are broken down into peptides and free amino acids whilst fat is broken down by lipase into free fatty acids. Catalase slows down the development of rancidity during the prolonged period of drying and maturing as this enzyme breaks hydrogen peroxide ( $\text{H}_2\text{O}_2$ ) down into water and oxygen ( $\text{O}_2$ ). The presence of  $\text{H}_2\text{O}_2$  would lead to the formation of free radicals if it were not broken down and rancidity would be speeded up as a result. *Staph. carnosus* tolerates up to 20% salt in water (almost saturated) and *Lb. pentosus* up to 9% salt in water. The presence of these two bacteria results in a minor decrease in pH value, which is a minor improvement towards the microbiological safety of the product as well. Protective cultures are also added to strengthen the competitive flora as well as for the reduction of nitrate to nitrite. Bacteria such as *Micrococcus* spp., *Pediococcus* spp. and *Staphylococcus* spp. are mainly applied for the reduction of nitrate as they possess the enzyme nitrate reductase; a certain level of nitrite added to the product during salting is always oxidized to nitrate and this nitrate is useless if not reduced again to nitrite. Enhanced levels of nitrite have a positive impact on curing colour and flavour and strengthen the ability of nitrite to act as a hurdle against microbiological spoilage. Some strains of *Staphylococcus* demonstrate some degree of nitrate-reducing activity even at low temperatures such as 5 °C and reduce  $\text{NO}_3$  to  $\text{NO}_2$  which is of benefit as salting takes place at temperatures around and up to 5 °C. Potassium sorbate is commonly applied to products within a 10–15% dipping solution to avoid growth of mould during drying.

### 23.3 Manufacturing technology

The manufacturing process of an air-dried product can be divided into three steps: salting, equalization of the curing additives introduced into the meat and drying. The drying stage is also known as maturing or ripening. Smoking, if it takes place, generally happens after equalization once the product is microbiologically stable. Diffusion is the primary process by which additives such as salt within muscle tissue and fat are distributed throughout the product.

#### 23.3.1 Salting and curing

During the initial manufacturing stage of salting (or curing), salt as well as other additives such as nitrite, colour enhancer and spices are applied to the surface of meat. During the manufacture of some products, such as Parma ham, salt is the only additive applied. The speed of diffusion of additives applied to the product is largely determined by the concentration of salt applied to the surface, the thickness of the piece of meat itself as well as the presence or lack of barriers, such as connective tissue, within the piece of meat itself. Intermuscular fat (fat between individual muscles), as is found in

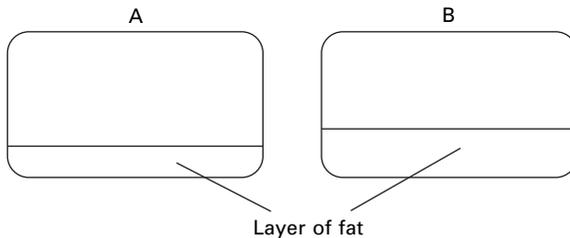
fatty meat such as pork neck or pork belly, also acts as a barrier and slows down diffusion processes.

Fat containing higher levels of unsaturated fatty acids reduces the speed of diffusion because this type of fat contains elevated levels of connective tissue compared with fat with mostly saturated fatty acids (see Chapter 1, Section 1.8). The speed of diffusion of additives such as salt can be enhanced by processing frozen and thawed meat as freezing destroys cells and cell membranes, which act as barriers if intact. Alternating tumbling of salted meat also speeds up diffusion as the repeated application and release of a vacuum loosens up the fibre structure, which in turn allows salt to penetrate more rapidly into the meat. Packing salted meat under a vacuum also loosens up the fibre structure and diffusion is enhanced. Salt is poorly soluble in fat and dissolves much better in lean meat as fat contains only a little water (around 12–15% compared with 75% water in muscle tissue). Salt added to pieces of meat, which are fatter than normal or showing a thicker layer of subcutaneous fat, will dissolve predominantly in the lean portion of the piece of meat. This part of the finished product will then display a noticeably enhanced level of salt even though the same amount of salt was introduced per kilogram of meat initially.

Figure 23.1 demonstrates the relation between the standard material A and a fattier piece of meat B, with the muscle tissue in product B containing more salt than that in product A.

### *Dry salting*

Dry salting is a very common method of applying curing additives to meat and is the method usually practised both when the meat to be processed is boneless and when large pieces of meat still containing bones are to be salted. Large pieces of meat such as pork legs (bone in or deboned) are generously salted and then placed on shelves in order for liquid to run off. After 2–3 weeks, the pieces of meat are salted again and placed back on the shelf. Salt and nitrite are applied twice as some of the salt and nitrite from the first application runs off with the water coming from the piece of meat and therefore not all salt applied penetrates into the meat. A second application of salt and nitrite also speeds up diffusion as the first load has already penetrated towards the core of the product. If large products are salted only

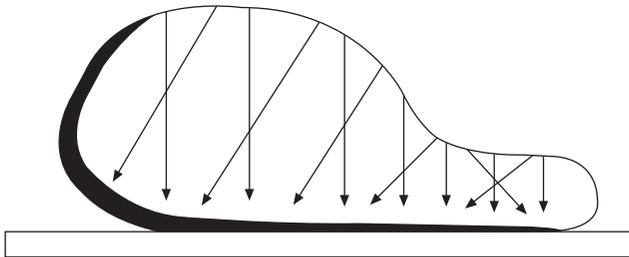


**Fig. 23.1** Comparison of standard and fatty meat.

once, the curing colour obtained in the core is frequently quite poor and a second load of nitrite is of great help for development of a strong curing colour throughout the product. The amount of salt applied during the two steps of salting depends largely on the experience of the person performing the task. Factories producing large volumes of these products have developed their own routine over a period of many years and often proceed even when the meat to be salted or the salt applied are not weighed; the finished products exhibit very similar levels of salt every time. Salted products with skin on are placed on racks with the skin facing the floor. The skin forms a natural barrier and when the meat side is facing up, salt penetrates more effectively into the meat.

During the two steps of salting (based on experience), in the manufacture of large products, around 30–35 g of salt are applied per kilogram of meat during the first salting step and another 15 g of salt are introduced per kilogram of meat during the second salting. More salt is applied on thicker parts of the piece of meat than on thinner parts. Within thicker areas of a piece of meat, salt has to diffuse more deeply and the distance of diffusion is longer than through thinner parts. Figure 23.2 shows a pork leg with greatly different distances through which the salt must penetrate. It is hard to give correct amounts of salt to be added as the sizes of the pieces of meat vary significantly. As stated earlier, experience is a key ingredient within the manufacture of dried products and producing a couple of batches gives all the answers needed. As soon as the process is fine tuned, factories commonly do not change the process once it is established. Large producers standardize their process in such a way that the size of pieces of meat to be salted and also quite frequently the thickness of the layers of subcutaneous fat have to be within a specified range. As a result of such standardization, the application of salt can be fine tuned. Consistent levels of salt are then achieved in the finished dried product as the loss in drying is also monitored on the basis of a predetermined percentage to be achieved.

Another method of dry salting is to apply salt and all other additives on to the surface of meat and then to place the salted pieces of meat into tubs or containers. The individual pieces are tightly arranged next to each other so that pockets, or spaces, between the individual pieces are avoided as much



**Fig. 23.2** A pork leg showing the various distances required for salt penetration.

as possible. This method is widely practised when boneless pieces of meat are processed; these pieces of meat can be placed easily into tubs since the removal of bones makes them easy to form. The actual process of salting can take place in several different ways under this method. One way is to rub all the additives on to the meat and the success of this method depends on the experience of the workers. Another way is to place the boneless pieces of meat in a mixer, or even tumbler, and to add additives based on the amount of meat to be salted. Therefore, the weight of meat to be salted is measured before placing the material into the tumbler (or mixer) and the amount of additives such as salt, nitrite, colour enhancer and spices applied is based on the measured weight. The process of mixing has to occur very gently so as not to destroy or tear apart pieces of meat. The mixing takes place at 0–3 °C for a short while, just long enough until all additives are evenly distributed. No protein must be activated on the surface of the salted piece of meat as activated protein would slow down drying significantly and can even cause microbiological spoilage of the product as sufficient moisture cannot be removed. An alternating vacuum can be applied during this salting process. The vacuum is established and released immediately several times to loosen up the muscle fiber structure. Additives, especially salt, diffuse into meat at a faster rate as a result. The application of all curing additives as well as spices within a gentle mixing process works best if all pieces of meat to be salted are of a similar sizes. If irregularly sized pieces of meat are introduced, often the larger pieces of meat obtain insufficient salt whilst smaller pieces of meat are over-salted. This is because smaller pieces of meat have a larger surface area in relation to their weight. Oversalting results in salty products whilst undersalted products present a microbiological risk as the hurdle  $A_w$  is created significantly later and bacteria can grow for a prolonged period of time until the  $A_w$  is established as a hurdle. When salting by hand or when using a mixing device, the products are generally salted once and the level of salt applied varies between 34 and 38 g per kilogram of meat. After the salted pieces of (mostly) boneless meat have been placed neatly into containers, all the material is left at temperatures of around 2–5 °C for around 2–3 weeks, depending on the thickness of the meat and the RH applied is 80–85%. Drying occurs at a slow rate during this period as the uptake of salt and equalization of additives within the piece of salted meat are the primary aims. During this time, brine is obtained within the containers or tubs owing to the high level of salt applied to the surface of meat; water penetrates from the core of the meat towards the outer layers at the same time as salt diffuses into the meat. The brine fills up the gaps between individual pieces of meat predominantly in the lower sections of the containers. In those areas, wet curing takes place because of the presence of brine and the pieces of meat are shifted around every week moving pieces of salted meat from the upper layers to the bottom in order that all pieces of meat are exposed to brine for a similar period of time. Therefore, this method of salting is a mix of dry and wet salting because the process starts as dry salting but moves partially over

to brine salting as brine obtained from meat itself is used. This self-developed brine is not present during dry salting in which the individual salted pieces of meat are placed on racks or shelves. If the pieces of meat lying for a long time inside brine are not moved around, over-salting will be the result as the brine is high in salt.

By applying a fair amount of salt to the surface of a piece of meat, the surface is basically exposed to 100% salt for a while and a salting-out effect takes place. Muscular protein exposed to concentrations of salt up to 5% swells and water is gained during swelling. The addition of 5% salt per kilogram of meat, in addition to the 1% salts present naturally in meat, adds up to 6% total salt. A maximum of 6% salt can be seen in meat before salting-out takes place and swelling is only seen up to that point. At concentrations of salt greater than 6%, water is released owing to the impact of salt and, as a much higher concentration of salt is present on the surface of freshly salted meat, water is removed. As a result of the removal of water from the outside layers in meat, the concentration of salt increases within those layers and therefore water penetrates from the core of the piece of meat towards the surface to compensate for the imbalance in salt concentrations (osmotic dehydration). At the same time, salt penetrates towards the core of the salted piece of meat. The basic principle behind all those processes of diffusion is that nature tries to attain an equilibrium and, to achieve that, water penetrates towards the salty areas and salt penetrates towards the non-salty areas, i.e. the core of the piece of meat. The speed of diffusion depends to a large extent on the difference between the salt concentration on the surface of meat and the salt concentration present in the core of the salted product. As a result, the speed of diffusion is greatest at the beginning of the salting process as high concentrations of salt are present on the surface whilst no added salt is yet present in the core. Over time, the different concentrations of salt balance out and the speed of diffusion slows down.

Another method of dry salting is to apply all curing additives at once to the surface of each individual piece of meat based on its weight. The products are then vacuum packed and stored at 2–5 °C. Salting in this way applies a fixed amount of salt per kilogram of meat and salt penetrates into meat under the effect of a vacuum. The application of a vacuum loosens up the muscle fibre structure and the speed of diffusion is enhanced.

Dry salting of meat using only nitrate is a method rarely practised nowadays. Nitrate is not a hurdle against microbiological growth and also does not support the formation of the desired red curing colour. To become active against microbiological growth and to support the formation of curing colour, nitrate first has to be reduced to nitrite, but the reduction of nitrate to nitrite only takes place at temperatures above 8 °C as the enzyme nitrate reductase only exhibits activity above this temperature. When nitrate is applied as the curing agent, then temperatures of 8 °C and above are required for the reduction of  $\text{NO}_3^-$  to  $\text{NO}_2^-$  but non-proteolytic strains of *Clostridium botulinum* type B can grow at such temperatures on the inside of the raw ham. As they

are non-proteolytic, these strains carry the danger that their presence can hardly be detected as no bad smell is obtained as the result of their presence. In addition, temperatures above 5 °C also allow *Salmonella* spp. and *Staph. aureus* to grow. Exposing salted meat to such elevated temperatures at the beginning of the manufacturing process presents a serious risk and this explains why, if nitrate is applied today, most commonly a mixture of nitrate and nitrite is used. When a nitrite–nitrate mix is added, the majority of the mixture is nitrite and some degree of nitrate is added for the stabilization of colour in products which are dried for a long period of time.

During the initial steps of salting, hurdles such as a high level of salt, the presence of nitrite, utilizing meat with a low bacteria count and, first and foremost, storing salted meat at temperatures below 5 °C avoids microbiological spoilage. *Salmonella* spp. as well as *Staph. aureus* cannot grow at temperatures below 5 °C. *Staph. aureus* is a lesser risk because this bacterium is normally not present within meat as it prefers aerobic conditions. If present on the surface, the high level of salt, in conjunction with nitrite and temperatures below 5 °C prevent *Staph. aureus* from growing. Hence, within the first 3–4 days after salting, the  $E_h$  value on the outer layers of the salted piece of meat is reduced and aerobic bacteria, including moulds and yeasts, are inhibited. The high concentration of salt on the other layers of salted meat reduces the  $A_w$  within these layers fairly quickly to 0.95, thus creating a hurdle against *Salmonella* spp.

### *Brine salting*

During brine salting, or wet curing, salt and other additives are not applied directly on to the surface of meat; the meat is instead placed into brine for a certain period of time, commonly using one of two methods. The level of salt within a brine can be expressed in percentage of salt within the brine as well as in degrees Baumé and, when a curing brine is prepared, care must be taken while performing calculations as the values in degrees Baumé are not exactly the same as the percentages of salt. When measuring salinity of a curing brine, a salinometer (salometer) is placed into the brine and, based on the density of the brine, the salinometer sinks to a greater or lesser degree into the solution and the degrees Baumé measurement is obtained. Increased density of the brine due to higher concentration of salt causes the salinometer to sink into the solution to a lesser degree. Table 23.1 shows the conversion of degrees Baumé to the kilograms of salt added per 100 l of water.

The first and most common method of brine salting utilizes curing brines containing around 20–24% salt, which is an almost saturated solution. Nitrite (around 0.2–0.3%) and colour enhancer are present in the brines and pieces of meat are placed in this brine generally in a ratio of 3:1 or 2:1 (only occasionally is a ratio of 1:1 utilized). More specifically, 300 kg of meat are covered with 100 l of a highly concentrated curing brine if a ratio of 3:1 is applied. As the meat is present in the brine, the individual pieces of meat take up a certain amount of salt which equalizes subsequently throughout the

**Table 23.1** The conversion of degrees Baumé to kilogram of salt added per 100 l of water

Baumé	Kilogram of salt added per 100 l of water
1	1.05
2	2.10
3	3.20
4	4.20
5	5.30
6	6.30
7	7.45
8	8.65
9	9.90
10	11.20
11	12.55
12	13.85
13	15.25
14	16.65
15	18.20
16	19.80
17	21.40
18	23.10
19	24.80
20	26.50
21	28.40
22	30.25
23	32.10
24	34.10
25	36.30

meat during the period of equalization. To be more precise, the pieces of meat are submerged in the brine until around 35 g of salt are obtained per kilogram of material. As a result of being submerged, the concentration of salt in the outer layers is initially much higher than in the inner areas of the product. Larger pieces of meat are placed in the brine for a prolonged period of time compared with smaller pieces of meat and 'experience' is a vital ingredient to obtain finished products displaying consistently similar levels of salt.

Either these almost saturated brines are prepared freshly every time or a 'live' brine is utilized. 'Live' brines are still in use in several countries such as the UK in the manufacture of Wiltshire bacon and a 'live' brine can be several years old. Salt and nitrite are constantly added to the live brine every time that meat is soaked to maintain certain levels of salt and nitrite as, every time that meat is placed in the brine and removed, the levels of salt and nitrite within the brine are reduced. The bacteria count of 'live' brine is around  $10^6$ – $10^8$  per millilitre of brine and, if the levels of salt and nitrite were not checked and maintained, unwanted strains from bacteria such as *Vibrio* spp. and *Leuconostoc* spp. would take over, thus enhancing the risk of obtaining a microbiologically spoiled brine. Foam on the brine as a result of

high enzyme activity as well as bad smell and the presence of slime clearly indicate microbiologically unstable brines. Microbiologically spoiled brines are reddish in colour and their pH value can have risen to a level of 6.5 and above. On the contrary, sour brines as a result of excess numbers of *Lactobacillus* spp. are dark brown in colour. Salt is commonly present in such 'live' brines at levels of between 22% and 24% (almost saturated) whilst nitrite and nitrate are present at around 0.4% (nitrite around 0.2–0.3%). These brines are stored under cold conditions at temperatures below 4 °C and variations in temperatures should be avoided. Therefore only well-chilled meat exhibiting a low bacteria count is placed into the brine. In addition, when no meat is to be placed in the brine for 1–2 days, it is kept agitated. Bacteria present within the brine are mostly coagulase negative *Staphylococcus* spp., *Lactobacillus* spp., *Micrococcus* spp. and sometimes Gram-negative rods from the genus *Vibrio*. These bacteria apply a specific flavour to the product as well as having a positive impact on the development of the curing colour and curing flavour. To imitate an old-style 'live' brine, starter cultures containing *Lactobacillus* spp. and *Micrococcus* spp. are utilized today in freshly prepared brines.

The ratio of meat placed into a certain amount of brine in freshly prepared or 'live' brines is of importance; when the ratio of meat to brine is reduced and the period of time for which the meat is left in the brine remains constant, a saltier product is the result. Placing excess amount of meat into a fixed amount of brine which demonstrates a certain level of salinity results in undersalted pieces of meat. Therefore, in order to achieve a constant product regarding the level of salt, the ratio of meat to brine has to be similar all the time or pieces of meat have to be submerged in the curing brine for different periods of time based on their size. If smaller pieces of meat were placed in a curing brine for as long as large pieces of meat, oversalted products would be obtained. Similarly, soaking large pieces of meat for the same time as small pieces of meat results in undersalted products. Once again, experience is a vital ingredient when producing air-dried products by the wet-curing method. Dry salting is somewhat simpler as the weight of the meat to be salted can be measured and a certain amount of salt and other additives applied per kilogram of meat. However, companies which have been practising brine salting for years have gained sufficient experience and produce perfect products all the time.

Another, more complicated and less frequently used method of brine salting is based on the fact that salt introduced into muscle meat by placing pieces of meat into a curing brine dissolves predominantly into lean muscle tissue which contains free water into which the salt can dissolve. Lean muscle tissue displays a water level of around 75% resulting in a solubility factor in lean meat ( $SF_M$ ) of 0.75. The solubility factor is heavily influenced by the amount of fat present on pieces of meat to be salted and the formula to calculate the solubility factor in fatty meat ( $SF_{FM}$ ) based on the varying level of fat is:

$$SF_{FM} \left( 1 - \frac{\% \text{fat}}{100} \right) \times 0.75 SF_M \quad [23.1]$$

As an example, if the meat to be salted displays a level of fat of 34%, the  $SF_{FM}$  would be 0.49. To calculate the correct concentration  $C_B$  of salt within the curing brine, a few parameters have to be known. For the purposes of this example, the meat:brine ratio will be taken to be 3:1, the concentration ( $C_P$ ) of salt required in the salted product is 3.2% and the level of fat on meat is 25%. Using the Equation [23.1], meat with 25% fat results in an  $SF_{FM}$  of 0.56. The formula to calculate the concentration ( $C_B$ ) of salt in brine would be

$$C_B = \frac{C_P (\text{meat:brine ratio} \times SF_{FM} + 1)}{SF_{FM}} \quad [23.2]$$

By putting all the above-mentioned parameters into the Equation [23.2], the following is obtained:

$$C_B = \frac{3.2(3 \times 0.56 + 1)}{0.56} \rightarrow 15.3 \quad [23.3]$$

As a result, the salt content of the curing brine is 15.3 kg per 100 l of brine.

In both methods, the level of salt taken up by the meat depends primarily on the level of salt within the brine, the period of time meat is placed in brine and also the meat:brine ratio. Other parameters such as the pH value of meat itself and the temperature of the meat in the brine have only a small impact on the amount of salt taken up by meat within a certain period of time. On average, pieces of meat are placed in brine for around 2–2.5 days per kilogram of meat, meaning that a piece of meat weighing 4 kg would be placed in brine for between 8 and 10 days. As stated earlier, experience is a highly desired attribute to have during the process of brine salting and companies follow processes that have been established over many years to produce products with consistent levels of salt and nitrite and of consistent quality. Besides experience, standardization of the process is another key factor for producing products of consistent quality. Standardization includes fixing the meat : brine ratio and following this standard so that the brine contains consistent levels of salt and nitrite. Pieces of meat of similar sizes have to be placed in brine for similar periods of time and be exposed to similar temperatures; otherwise, if these variables were changed, the result would be an inconsistent product.

It is problematic to dispose of a wet-curing brine, or brine obtained by placing salted pieces of meat into a container, because the brines exhibit generally an extremely large number of bacteria and, if introduced into the sewage system of a small village or town, the entire sewage system can be disturbed. Occasionally, highly concentrated brine is injected into pieces of meat to be salted and the level of injection is between 6% and 8%. This process has the advantage that salt, nitrite and other additives are introduced

into all areas of meat at the same time. However, extreme care has to be taken that the injector utilized is clean as bacteria such as *Enterobacteriaceae* could be introduced right into the core of an air-dried product, which is never heat treated thus creating a serious microbiological risk. If injecting only 6–8% brine and with the desired level of salt in the meat after injection being around 3.5%, the concentration of salt in the brine would need to be 50%, which exceeds the maximum level of solubility of salt in water by far. As a result, 6–8% of a brine containing 15–20% salt is injected initially and additional salt is afterwards applied on to the surface of the injected meat to achieve the desired total concentration of salt. Another risk when injecting highly concentrated brines is that even slight variations in the level of injection result in significant variations of salt introduced per kilogram of meat and an inconsistent level of salt will be seen in the final product. Injection of meat takes place commonly if products are produced quickly and the water introduced is removed afterwards by placing the injected meat into a press. The introduction of salt and nitrite directly into the core makes the product safe from a microbiological point of view at an earlier stage than if it were dry salted, thus allowing the product to be smoked and dried at higher temperatures soon afterwards. The development of a distinctive curing flavour, which primarily depends on allowing sufficient time for processes such as proteolysis and lipolysis, is not desired in these fast-produced products. The typical curing and raw ham flavour is generally not wanted in these products and in any case cannot be obtained as the time required for enhanced enzyme activity is simply not available.

After salting, where the necessary amount of salt and other additives were introduced into meat by dry salting, by a mix of dry and wet salting or by brine salting, the second stage of the production process is equalization of all additives. The additives introduced penetrate into all areas of salted meat via processes of diffusion. During equalization of curing additives the  $A_w$  is reduced to 0.95, which is an important microbiological hurdle. The borderline between the processing steps of salting and equalization cannot be clearly defined as one leads into the next and penetration of salt into the inner layers of meat already starts during the salting period. Expressed simply, all the salt and other additives needed are taken up by the meat during salting, predominantly into the outer layers, and equalization of the additives takes place afterwards. Equalization of the curing additives introduced generally takes place in a ratio of 40:60 in relation to salting time. For example, a piece of meat which was salted and placed in the container for 2 weeks in total during salting is removed from the tub and placed for another 3 weeks under cold conditions for equalization. Another rule commonly applied is the  $\frac{1}{3} : \frac{2}{3}$  rule, which means that the time for equalization lasts twice as long as the period of salting.

Equalization takes place at temperatures between 2 and 5 °C as the core of the salted piece of meat is not microbiologically stable until the level of salt in those core areas has reached around 4.5%. During equalization, the

level of salt reaches around 4.5% in all areas within the piece of meat and the loss in weight experienced during salting, as well as during equalization, contributes to the increase in the level of salt. At the same time, the  $A_w$  drops to 0.95, which makes the product stable against Enterobacteriaceae such as *Salmonella* spp. and *Escherichia coli*. It is common practice that pieces of meat are placed into a form or press during equalization to speed up the loss in moisture as well as to shape the product. Salted products are frequently filled into fibrous casings or nettings during equalization which permit hanging of the product on to trolleys. Placing the salted product into a fibrous casing also reduces the risk that a dry ring is obtained or that case hardening takes place during drying. The fibrous casing also ensures that any mould (which should not be present initially) grows on the casing instead of on the product itself. If the salted product is filled into fibrous casings, a casing with the correct diameter has to be chosen so that the product just fits into the casing and there is no air-containing space between product and the casing. Loosely packed products have some space between the product and the casing and mould can grow in those areas quickly. During the process of equalization, salt penetrates towards the core of the meat whilst water penetrates at the same time towards the surface. As in raw fermented salami, the increased level of salt in the outer layers causes the water to penetrate towards those layers as nature tries to balance out the concentration of salt. At the same time, slow drying of the product during equalization maintains an increased level of salt on the outer layers of the product. As moisture is constantly removed and the level of salt is therefore permanently higher in these outer layers of meat than in the core of the product, moisture continuously penetrates towards the surface where it is removed. The RH applied during equalization is between 75% and 85%, thus removing moisture from the surface of the salted piece of meat. The equalization of additives, such as salt, takes place at a similar speed at temperatures such as 5 °C or 8 °C as diffusion processes of salt do not depend significantly on temperature. However, the microbiological risk obtained by placing non-stable salted meat not exhibiting an  $A_w$  of 0.95 in the core at elevated temperatures such as 8 °C is significantly higher. Equalization taking place at elevated temperatures is certainly beneficial for the reduction of nitrate to nitrite if nitrate has been added but the microbiological risk is ever present and, as stated, diffusion of salt is not speeded up. The temperature applied during equalization should not exceed 5 °C as some cold-tolerant non-proteolytic strains of *Cl. botulinum* type B as well as *Staph. aureus* can grow at temperatures above 5 °C.

If the factor 'time' is in place as a critical control point (CCP) during salting and equalization, the same amount of salt, nitrite and all other additives have to be applied per kilogram of meat to be salted. The storage temperatures of salted meat have to be the same during salting and equalization to achieve similar levels of salt in all areas within the salted piece of meat within the standard period of time under set temperatures. Significant differences in uptake and diffusion of salt into the product can be seen during the salting

period if meat is stored at 1 °C or, on the other hand, at 5 °C. It is also essential that the pieces of meat are of a similar sizes, or thicknesses, as larger pieces of meat require longer time until an  $A_w$  of 0.95 is reached in all areas of the salted piece of meat. A set (standardized) temperature during salting and equalization of additives is also essential to achieve similar speeds of diffusion within a set period of time. Once the product is microbiologically stable exhibiting an  $A_w$  of 0.95 within all areas of the salted meat, the meat can be exposed to higher temperatures to start fermentation, which plays a vital role in the development of the curing flavour as well as the drying process. Products exposed to temperatures such as 22–24 °C too early when they do not have an  $A_w$  at 0.95 commonly experience the formation of gas and ‘ballooning’ is seen. Ballooning, or the formation of gas, can be detected by pressing the thumb on the knee joint of a salted piece of leg (bone in). If the pressure mark disappears right away and does not stay there for a while, gas is present within the product which eventually leads to spoilage.

### 23.3.2 Smoking, maturing and drying

Upon completion of equalization when a microbiologically stable product exhibiting an  $A_w$  of 0.95 has been obtained, the products are removed from rooms at a temperature of 2–5 °C and exposed to temperatures around 22–24 °C to kick-start enzyme activity. They remain at this temperature for around 24–48 h. Subsequently, the temperature is reduced to 16–18 °C and an RH of around 76–80% is applied for 2–3 days. If the product is to be smoked, cold smoke is applied to the product for the first time once the product has been removed from the chilling temperature. The temperature during smoking is between 20 and 25 °C. The amount of smoke applied varies dramatically and depends largely on the flavour and colour intensity wanted. It is common practice to apply cold smoke twice or three times per day for around 1–2 h and this procedure is repeated as often as is desired. Smoke (see Chapter 6, Section 6.11) has an impact on the colour, flavour and shelf life of the product because of the components present within the smoke. Components such as different organic acids, phenols, carbonyls and formaldehyde help to preserve the product and also to delay, or prevent, growth of unwanted mould. After a few days, the temperature is reduced to around 12–15 °C and the RH is lowered to 72–75%, which starts the drying stage.

The air speed is low during drying at around 0.3–0.4 m/s. During the final stages of drying, the air speed is only around 0.1 m/s as a high air speed increases the risk of case hardening or the formation of a dry ring on the outside of the product. As stated earlier, products are commonly packed into fibrous casings or in a netting as those materials create a layer between the product to be dried and the passing air, thus reducing the risk that case hardening occurs. The overall aim during drying is, as in the case of fermented

salami, to remove moisture as quickly as possible without obtaining case hardening and, once again, experience plays an important role here.

Parameters such as the filling level of the drying room as well as the size of the piece of meat to be dried determine the speed of drying. Generally, parameters such as the elevated air speed, elevated temperatures and reduced levels of RH speed up drying whilst the speed of drying, or the amount of moisture removed from the product within a certain period of time, is slowed down by reduced temperatures, reduced air speed and increased levels of RH. The speed of drying is also slowed down the longer the product has already been dried. Less moisture is removed from the product later in the drying period within a certain period of time as higher levels of free water are present at the initial stages of drying whilst less free (unbound) water is present within the product when prolonged periods of drying have already taken place. Growth of mould can be avoided during drying by the application of smoke before any signs of mould are visible on the product. It is also possible to prevent mould growth by dipping the product into a 10–15% potassium sorbate solution before or after smoking. The combination of smoke and potassium sorbate applied to the product whilst no mould is visible is a powerful means of avoiding growth of unwanted mould. However, if the product is smoked right after equalization comes to an end, growth of mould can be prevented in most cases without having to apply potassium sorbate. Several countries have maximum legal limits in place for sorbate present on the outer layers of the finished product and it is the dipping time and the concentration of sorbate within the solution which determine the level of sorbate present in the finished product. Generally, dipping of the product in a 10–15% solution for a few seconds does not cause the legal maximum limit to be exceeded. The use of sorbate has to be declared on the label of the finished product so that the customer is aware that the surface has been treated with sorbate.

During drying, important processes such as weight loss, development of flavour and tenderization of the product take place. The loss in weight applies firmness to the product and enhances sliceability, which is significant as air-dried products are commonly sliced very thinly before consumption. After a prolonged period of drying, the  $A_w$  drops below 0.89 and the product becomes shelf stable without having to be refrigerated. At or below an  $A_w$  of 0.89, the two main risks from a microbiological point of view, *Salmonella* spp. as well as *Staph. aureus*, are well controlled and neither of these can grow or produce toxin any longer.

Flavour development is the other major occurrence during drying as raw meat itself does not demonstrate a great deal of flavour. During drying, biochemical changes such as proteolysis and lipolysis take place within the product and enzymes such as protease and lipase are active. Flavour development during proteolysis is predominately due to enzymes (proteases) such as cathepsins and calpain and is based on bacterial activity. Different types of calpain seem to make a major contribution during the initial stages

of maturing (drying) whilst cathepsins are still active during drying long after calpains have ceased to be active. Different types of cathepsins such as cathepsins L, D, H and B are involved in proteolysis and this takes place at different speeds among different animal breeds of the same species. For example, the amounts of proteases in Pietrain and German Landrace pigs are not the same; German Landrace pigs generally exhibit higher protease activity than Pietrain pigs do. In fact, other animals such as poultry show significantly higher enzyme activity overall than pigs do.

The flavour obtained also contains commonly volatile compounds from enzymatic oxidation of unsaturated fatty acids and further interaction with peptides, proteins and free amino acids. Around 250 volatile compounds are known to be present in the flavour overall. In air-dried products, non-volatile flavour compounds such as peptides and free amino acids contribute to flavour whereas the same substances have an even more significant impact on the flavour of raw meat during ageing. Aminopeptidase is another enzyme present in meat, which contributes to the formation of free amino acids.

Enzymes such as lipases, which break down fat into glycerol and free fatty acids, such as stearic, linoleic, palmitic and oleic acids are present within meat as well and are found in lysosome as well as muscle tissue. Microorganisms play a minor role in the contribution of lipolysis towards flavour, and enzymes are chiefly responsible for that once again. The activity of the enzyme lipases comes more or less to a stop after drying for around 6–8 months. Lipases are active in salty and lower water activity environments which favours their action during prolonged periods of drying. This also explains the fact that only a small degree of lipolysis takes place during the initial stages of salting and equalization within the production of products dried for a short time because the  $A_w$  is still high and the concentration of salt quite low overall as little drying has taken place. Such products lack flavours originating from lipolysis as well as proteolysis, as the time required for the development of those flavours, based on free fatty acids as well as free amino acids, has not been provided. Neutral and alkaline lipases from adipose fat are very active during salting and drying and only neutral lipases remain active during drying for a prolonged period of time. Fatty acids such as linolenic acid, oleic acid and myristic acid, as well as other monounsaturated and polyunsaturated fatty acids, have a significant impact on flavours formed following lipolysis. In turn, the formation of those fatty acids depends largely on the feed given to pigs. The development of the typical slightly cheesy flavour seen in products such as Parma ham and prosciutto, which is a combination of enzyme activity such as proteases, lipases, collagenase and many other biochemical processes, requires a drying period of around 6–8 months. Products that are dried longer develop flavour even more strongly and also different types of flavour but are only detected by experts.

Tenderness of meat is enhanced greatly during drying as well. During maturation or drying over several weeks or even months, the structure of myosin and other proteins such as desmin, nebulin and titin within lean

muscle meat is degraded and is finally lost completely, increasing tenderness. Enzymes, predominately proteases, perform this task in conjunction with the enzyme collagenase, which specifically softens collagen therefore contributing to tenderness of the product as well.

Tenderness overall is the result of the breakdown of proteins as well as the loosening up of collagen, and the enzymes involved should be seen as having a joint impact. When a product is dried too slowly over a prolonged period of time, excess proteolysis results in a soft and mushy texture. This is due to the high concentration of low-molecular-weight nitrogen compounds such as peptides and free amino acids. Sometimes, this can even lead to a bitter and metallic taste. In products dried for a long time, the pH value commonly rises above 6.2 as a result of highly alkaline metabolic by-products from enzyme activity (proteases), which is not a disadvantage. At this stage, various types of protease do not degrade or tenderize meat any longer but contribute rather to flavour.

The variation in enzyme activity over prolonged periods of drying explains why products dried for a short time taste more salty than products dried for a long time even though there is the same level of salt in both types of finished product. Products dried for a short time demonstrate a higher  $A_w$  and do not contain flavour components originating from enzyme activity. Chloride ions, which come from salt and are mainly responsible for the salty taste, dissociate to a larger degree in products with a higher level of free water than in a product with less free water, resulting in an enhanced salty taste. Therefore the level of free water within products having the same level of salt creates different levels of saltiness depending on the rate of dissociation of salt. Salt is also bound more firmly within proteins in meat products dried for prolonged periods of time and is not as easily removed during chewing compared with salt in products exhibiting a higher level of free water, or  $A_w$  value. Simply expressed, an air-dried product displaying a level of salt of 4.6% in the finished product, as well as an  $A_w$  of 0.91, tastes saltier than another product exhibiting the same level of salt but an  $A_w$  of 0.87. The colour in a cured air-dried product, obtained via the impact of nitrite and supported by colour enhancers, is stabilized by the combination of a low water activity in conjunction with a high concentration of salt obtained during drying. Those two factors in combination denature proteins, including nitrosomyoglobin, and therefore fixate the curing colour. However, air-dried products produced within a short period of time and still exhibiting an  $A_w$  around 0.91–0.92 frequently display poor colour because the nitrosomyoglobin has not been effectively denatured by a combination of low  $A_w$  and a high concentration of salt. Higher levels of drying also result in a stronger curing colour within the product overall as a reduced moisture content is closely associated with an elevated content in nitrosomyoglobin at the same time.

Once the desired level of drying has been obtained, whilst the product is stored at 12–15 °C and 70–75% RH, casings or nettings are removed. Shelf-stable products exhibit an  $A_w$  of below 0.89 at this time. Other products, as

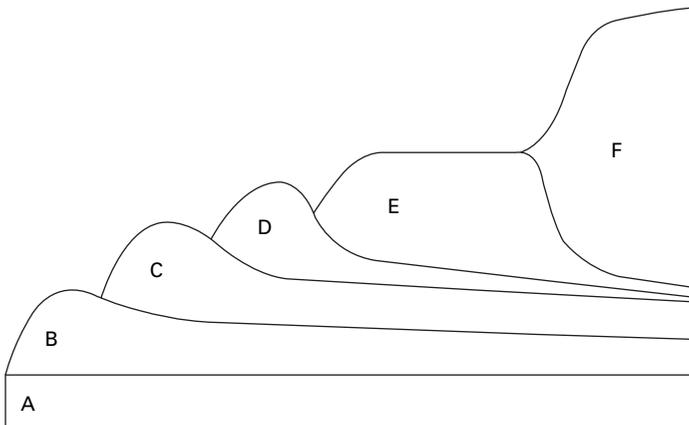
a result of significantly less drying, display an  $A_w$  of around 0.91–0.92 and are therefore not shelf stable without being stored at temperatures below 4 °C. The reason for not obtaining an  $A_w$  of 0.89 or below is that there is a significant difference in weight loss required to produce a product with an  $A_w$  of 0.89 compared with that with an  $A_w$  of 0.92. Products exhibiting an  $A_w$  of 0.91–0.92 contain considerably more moisture and can be sold more cheaply than fully dried products, displaying an  $A_w$  of 0.89 or below. However, the characteristic flavour and texture of a cured dried meat product are missing to a large degree in products high in  $A_w$ .

Figure 23.3 demonstrates the sequence of hurdles within raw air-dried products when using meat with a low bacteria count.

### 23.3.3 Slicing, packing, storage

Many dried products are shaped before being sliced or cut into halves, but some are packed as whole pieces. Pieces of meat which have been salted and dried with the bone in are deboned using particular holding tools attached to the boning table before being sliced or packed, or packed as whole pieces without being sliced. Products such as Parma ham and other products produced in Spain and France are frequently sold with the bone still in the product.

Boneless products sold as whole pieces or cut in halves are predominantly vacuum packed or packed into vacuum shrink-bags being dipped into hot water at 90 °C for a few seconds. This allows the bag to shrink and align itself tightly to the product and the dipping process also destroys any bacteria present on the surface of the product which may have been introduced into the product during packing. Packing under vacuum stops any further moisture



**Fig. 23.3** The sequence of hurdles in the production of raw air-dried meat: A, meat with a low bacteria count; B, selection of material showing a pH value below 5.8; C, addition of preservatives such as nitrite and salt; D, reduction in the  $E_h$  value; E, storage of the salted product below 5°C until an  $A_w$  value of 0.95 is obtained; F, reduction in the  $A_w$  value, subsequently leading to an  $A_w$  value below 0.89.

loss in the product as well as inhibiting the growth of aerobic bacteria and yeast or mould. Products sold vacuum packed as a whole piece, cut into halves or as thick slices, exhibiting an  $A_w$  of below 0.89, are shelf stable without refrigeration because the growth of bacteria such as Enterobacteriaceae and *Staph. aureus* or the formation of toxin is inhibited. Care has to be taken that condensation water does not form during packing as this condensation water would create an  $A_w$  of 1.00 on the surface of the product and it would not be shelf stable any longer as bacteria would find sufficient water to grow.

Formation of condensation water is generally not a problem in products packed as a whole piece, cut into halves or as thick slices of around 2–5 cm because cutting into halves or thick slices does not require the product to have cooled prior to being cut. If the dried product is removed from the drying room, which commonly displays a temperature between 12 and 15 °C, into the slicing or packing room, no condensation water is obtained as the slicing or packing room is generally at a lower temperature than or similar temperature to the product itself. If the product is thinly sliced, and a large quantity of air-dried products are sold in this way, the scenario is totally different. The process of slicing itself always recontaminates the product slices to a certain degree and in addition, to improve the sliceability of especially formed products, the products are often placed in rooms exhibiting subzero temperatures prior to slicing. Once such products are placed in the slicing room, which has a significantly higher temperature than the surface of the product, condensation water commonly forms on the surface of the product as the dew point is exceeded (see Chapter 4, Section 4.12). Products to be sliced very thinly have to be well cooled and are even commonly sliced when slightly frozen. The high concentration of salt within the product does not allow water to freeze even at subzero temperatures and products can be sliced into thin slices more effectively when cooled. Because condensation water generally forms during slicing of such well-chilled or slightly frozen products and therefore  $A_w$  is no longer a hurdle against microbial growth, the sliced product is stored under refrigerated conditions at temperatures below 4 °C. Sliced products are frequently sold in modified-atmosphere packaging, using good-quality packaging materials as these products are generally of high value, based on their high weight loss during drying as well as the fact that the raw materials were expensive cuts, such as leg or loin, in the first place. Modified-atmosphere-packed products commonly experience a gas mix of 30–40% CO<sub>2</sub> and 60–70% N<sub>2</sub>. The CO<sub>2</sub> on the surface of the product turns into carbonic acid, which acts as the shelf-life-extending agent. CO<sub>2</sub> also interferes with metabolic activities in cell membranes of countless bacteria, thus delaying bacterial growth once more. N<sub>2</sub>, which is an inert gas, does not react with anything inside the product and is applied as a filler to replace O<sub>2</sub>. The level of O<sub>2</sub> within the gas mix should be below 1% and levels of 0.5% or below would be optimal. Packaging material utilized should demonstrate high barrier properties against O<sub>2</sub> and moisture as any diffusion of those

substances into the packaging shortens shelf life and/or causes change in colour and flavour.

A large amount of sliced products are also packed under vacuum and this method of packaging also inhibits the growth of mould on the product as no  $O_2$  is available for aerobic fungi. A major disadvantage of packaging sliced products under vacuum compared with in a modified atmosphere is that the application of vacuum causes the individual slices to stick together and they are very hard to separate afterwards, especially as the slices themselves are very thin. Occasionally, the formation of gas can be observed in vacuum-packed products and heterofermentative *Lactobacillus* spp. are commonly the cause. The formation of gas can often be avoided by proper and sufficient drying of the product to reach an  $A_w$  of 0.90 or below at which *Lactobacillus* spp. are not active any longer.

### 23.3.4 Microbiology in air-dried products

Bacteria such as *Salmonella* spp. and *Staph. aureus* are the major risks in the production of air-dried products. The risk of *Salmonella* spp. can be controlled, firstly, by processing meat which is very low or even free of *Salmonella* spp. in first place and, secondly, by using well-chilled meat and by salting the meat at temperatures below 5 °C. Growth of *Staph. aureus*, lactic acid bacteria as well as other members of the family Enterobacteriaceae is also inhibited below 5 °C. In addition, Enterobacteriaceae are inhibited by an  $A_w$  of 0.95 and salted products are only exposed to elevated temperatures for fermentation and subsequent drying once the  $A_w$  in all areas within the salted piece of meat has dropped to 0.95. *Staph. aureus*, which produces a toxin at  $A_w$  levels above 0.89, is not a great problem in the production of cured air-dried meat products because this bacterium prefers aerobic conditions for growth and is therefore generally only a risk on the surface of meat as the inner sections of meat exhibit anaerobic conditions. On the surface of salted meat, the extremely high concentration of salt (almost 100%), the presence of nitrite and the low temperatures applied during salting and equalization keep growth of *Staph. aureus* well under control. The high concentration of salt on the surface of salted meat also reduces the  $A_w$  in those outer layers fairly quickly to levels around 0.91–0.92, which is an additional partial hurdle against *Staph. aureus*.

Cold-tolerant Enterobacteriaceae such as *Proteus* spp., *Serratia* spp. and *Enterobacter* spp. can be a problem but utilizing meat with a low bacteria count from the beginning and raising the temperature above 5 °C only once the  $A_w$  is at 0.95 in conjunction with the presence of salt and nitrite controls those bacteria well. Cold-tolerant strains of *Cl. botulinum* types E and B can present a problem if salted meat, not stabilized yet by an  $A_w$  of 0.95, is exposed to temperatures above 5 °C. The majority of microbiological spoilage in air-dried products is caused by Enterobacteriaceae and *Staph. aureus*, with lactic acid bacteria being rarely responsible for spoilage.

Unwanted bacteria are introduced either from the outside (slimy surface

of meat to be processed, deep cuts introduced during boning, and unhygienic handling before salting) or from the inside. Spoilage of products from the inside out is mainly seen when processing DFD meat owing to insufficient acidification of meat itself during rigor mortis or when salted meat has been exposed to higher temperatures (above 5 °C) before an  $A_w$  of 0.95 is reached in all areas within the piece of meat.

Spoilage starting from the inside is frequently caused, or supported, by cold-tolerant Enterobacteriaceae such as *Enterobacter* spp., *Proteus* spp., *Citrobacter* spp. and especially *Serratia* spp. which have been present in meat since slaughtering. Spoilage from the inside can take place in bone-in products, as bacteria within the bone marrow penetrate into muscle tissue ultimately causing spoilage. The presence of Enterobacteriaceae in numbers above  $10^6$  per gram of product and a total bacteria count of  $10^8$ – $10^9$  per gram of product including *Bacillus* spp. and *Sarcina* spp. (family Micrococcaceae) results in spoilage. In addition, members of the genera *Clostridium* and *Staphylococcus* are also regularly seen in spoiled products.

Mould is generally not desired on air-dried products and should be avoided. Drying rooms in companies in Italy and other places, however, display an enormous degree of mould which covers the entire surface of the product. None of these moulds produce mycotoxins and all the moulds are part of the house flora, which applies a specific taste and flavour to the product. Mould can be avoided, as stated earlier, through timely application of smoke as well as by dipping the smoked products into a 10–15% solution of potassium sorbate. *Aspergillus flavus*, *Penicillium viridicatum* and *Fusarium culmorum* are the organisms most likely to cause unwanted mould, but growth of *A. flavus* is largely inhibited in a product with an  $A_w$  of or below 0.90 as well as when the RH is below 75% within the drying room. Mould-infested drying rooms can be cleaned with an alkaline cleaning detergent as moulds are more effectively removed by the application of an alkaline substance than by an acid material. After rinsing the cleaned room well with water, a 5% potassium sorbate solution can be sprayed which is left to dry without being rinsed afterwards. It is important that all cleaning materials utilized initially are removed as fungal spores would be easily introduced and the problem start again.

Other bacteria such as *Micrococcus* spp. are desired in air-dried products as they contribute to a stable and strong curing colour and also possess the enzyme catalase which breaks down hydrogen peroxide, thus delaying rancidity in products dried for a long time. The microflora present in air-dried products commonly consists of lactic acid bacteria, with *Lactobacillus* and *Pediococcus* being the predominant genera. *Staph. carnosus* as well as *Staph. xylosus* are frequently found in a finished product and counts between  $10^5$  and  $10^6$  per gram of product are frequently seen if the genera *Staphylococcus*, *Micrococcus* and *Pediococcus* are counted together. *Micrococcus* spp. and *Lactobacillus* spp. can add up to  $10^4$ – $10^5$  per gram of product, which is generally not of concern. However, high numbers of *Serratia liquefaciens* are quite often the

reason for spoiled products. Mites are occasionally introduced on to the surface of air-dried products (in countries where this is permitted). Many people find this disgusting, but mites contribute very positively to flavour. The mites are thoroughly washed off with a salt solution prior to packaging of the product.

### **23.4 Summary of critical production issues**

- 1 Meat should exhibit a low bacteria count ( $10^2$ – $10^4$  per gram of product), a pH value between 5.5 and 5.8 as well as being well chilled (0–2 °C) prior to application of salt.
- 2 Growth of bacteria should be avoided during thawing of frozen meat.
- 3 Cuts into meat during boning should be avoided and DFD beef should not be processed.
- 4 As much connective tissue as possible should be removed during trimming for faster penetration of salt into the meat.
- 5 Salt should be applied at around 35 g per kilogram of product through dry salting, by a combination of dry and wet salting or by the application of brine salting.
- 6 Nitrite should be added at the maximum permitted level.
- 7 Salting should take place at a temperature below 5 °C and an RH of around 85%.
- 8 Equalization of curing additives is carried out at a temperature below 5 °C and an RH of around 80% until an  $A_w$  of 0.95 is obtained in all areas of meat.
- 9 Following equalization, meat is to be held at 22–24 °C for around 24–48 h to start fermentation and enzyme activity.
- 10 Application of cold smoke (if part of the manufacturing process) should be performed at around 20–25 °C and an RH of 80%.
- 11 Products should be further dried at 16–18 °C and around 75–80% RH for a few days.
- 12 Final drying and storage of product is carried out at 12–15 °C and 72–75% RH; the loss in drying is between 25% and 40%.
- 13 Non-sliced products are commonly packed under vacuum and are shelf stable if the  $A_w$  is below 0.89 and no condensation water was formed during packing.
- 14 Sliced products are generally modified atmosphere packed as well as packed under vacuum and stored at temperatures below 4 °C.

## 24

# Typical cured air-dried meat products from around the world

### 24.1 Parma ham (Italy)

Parma ham or prosciutto di Parma is produced in the area around Parma in Italy and each ham carries the symbol of Parma, the five-pointed coronet (corona ducale) symbolizing the Grand Duchy of Parma. Pigs utilized for production of Parma ham must come from northern and central Italy and the feeding of pigs to be processed for Parma ham is commonly tightly controlled. The pig feed used has an impact on the fatty acids present in the pig fat, which in turn have a significant impact on flavour development caused by lipases during the long period of drying. Legs, which have a maximum weight of around 13 kg but a minimum weight of 9 kg, are salted and all raw materials are chilled to around 0 °C for 1–2 days before being salted. The pigs to be slaughtered have to weigh at least 140 kg. Prior to salting, the legs are massaged to remove the last traces of blood before salt is applied by hand. Around 25 g of salt (sea salt) are applied per kilogram of meat during first salting and, generally, traditional Parma ham is produced without the addition of nitrite or colour enhancer; however, some nitrate is occasionally added.

The salted product is placed on racks at a temperature of 1–4 °C for around 1 month and some additional salt (around 5–10 g per kilogram of product) is commonly applied around 7–10 days after the first salting took place. During this month, the brine obtained as a result of salting runs off. After a month, the distribution of salt in the ham is equalized by hanging up the legs at a temperature of 3–5 °C for around 2 months. Excess salt is also removed before hanging. The loss in weight during the period of 3 months is between 12% and 15% as the RH applied during this period of time is

between 75% and 85% and lean pork legs lose more weight than fatty pieces of legs. Occasionally, to remove excess salt, the salted legs are washed after salting for around 1 month and then stored in a dry room for 1–2 days at around 70–74% RH to dry the surface quickly again. Quite a low level of salt is applied overall because the product is kept for 3 months at temperatures below 5 °C, which keeps the products safe from a microbiological point of view. Meat with a low bacteria count is also used in the first place. Following the 3 months in which the product has been salted and dried, the product is then commonly placed for 4–6 days at a temperature of 20–22 °C so that fermentation and enzyme activity for flavour development can begin.

Traditional Parma ham is not smoked and instead further drying takes place. The next 3–8 months of drying occurs at temperatures of 14–16 °C and at an RH of between 70% and 74% in conditions with some degree of air circulation. In the past, racks were left in the open on terraces for air to circulate freely and were covered by a net to keep insects away. Factories are built at 90° to a river, which keeps the level of moisture constant as well as causing some air circulation as well.

After 7 months from the first day of salting, the ham has lost around 22–25% in weight. The open meat surface is covered with a mixture of flare fat, pepper, rosemary (to avoid rancidity) and some salt; a small area next to the skin on the topside is not covered as a small ‘corona’ is left for the ham to breathe, while not allowing it to lose much more weight quickly. The ham is dried continuously at 14–16 °C and an RH between 70% and 74% for another 3–5 months, but only another 5% in weight is lost in these months as the open meat area has been covered. During these 3–5 months, development of flavour takes place as a result of proteolysis as well as lipolysis and free fatty acids as well as peptides and free amino acids are formed. Tenderization of muscle tissue also takes place because the collagenase activity loosens up the structure of intramuscular collagen.

After around 1 year the aroma of the ham is inspected by sticking a bone (tibia from a horse) several times into the knuckle and upper area of the ham, thus checking the flavour obtained on the bone. Highly specialized people perform this smell test, to detect whether the ham is ready for sale or whether some further drying is required to obtain the desired flavour. After around 12–14 months the ham has lost around 30% in weight and is ready for sale. Most of the finished products are sold with the bone still in, but some hams are deboned before being vacuum packed. Deboned products are also commonly sliced and modified atmosphere packaging is preferred for sliced hams. Even after drying for 12–14 months the level of salt is only around 4.7–5% and the TPC on Parma ham is between  $10^4$  and  $10^6$  per gram of product. Interestingly, Parma ham has a red colour even though no nitrite, nitrate or spices possibly containing nitrate have been added. The red colour is due to the reduced myoglobin in the ham as the oxygen pressure within the product is very low (below 4 Torr) after the long period of drying. Myoglobin in its pure form, with no oxymyoglobin and very little metmyoglobin, is

obtained and pure myoglobin is of reddish colour. In addition, bacteria such as *Staphylococcus epidermidis*, *Staph. lentus* and *Staph. warneri* are able to turn metmyoglobin partly into myoglobin, thus supporting the red colour exhibited in the finished product.

## 24.2 Pancetta (Italy)

Pancetta is produced from lean deboned pork belly, commonly with the cartilage removed. The pork skin is removed and the meat is then salted using around 25–30 g of salt per kilogram of meat, nitrite, occasionally some nitrate, ascorbate (0.5–0.8 g per kilogram of product) as well as spices such as ground black pepper, chilli, garlic, juniper and rosemary. Sugar is added as well at a level of around 3–5 g per kilogram of meat. The salted pork bellies are placed in tubs for 10–14 days at temperatures of between 2 and 5 °C at 80–85% RH. All the raw materials are moved around after almost 5 days as brine forms at the bottom of the tub. The salted product is then rolled and placed tightly into nettings or fibrous casings before being exposed to temperatures around 22–24 °C for 24–36 h to start enzyme activity. The materials are rolled in such a way that the meat side of the belly forms the core of the roll whilst the outer layers, containing the layers of fat, are on the outside covering the meaty core. During this period of time, cold smoke is applied several times in order to obtain the desired smoke colour and flavour as well as to inhibit unwanted growth of mould. Once smoked, the product is held at temperatures of 12–14 °C at an RH of 72–75% for further drying which normally lasts between 3–4 weeks. The presence of a casing around the product during drying helps to avoid case hardening and the loss in weight is around 30% overall.

## 24.3 Parma coppa (Italy)

Parma coppa is made from boneless pork neck with subcutaneous fat (including skin) removed. The well-chilled (0–2 °C) meat material is salted by applying around 30–35 g of salt per kilogram of meat and nitrite, ascorbate and sugar (3–5 g/kg) are added. Further processing stages are very similar to those used to manufacture pancetta; the salted products are placed into tubs for around 2–3 weeks under chilled conditions and an RH of 80–85%, and the salted materials are turned upside down every week. The salted pieces are then packed tightly into fibrous casings and the filled products are commonly left standing for 5–7 days under chilled conditions or placed in a press for several days to flatten the product as well as to press out moisture, thus reducing subsequent drying time. The product is then exposed to temperatures of 22–24 °C to start enzyme activity and cold smoke is applied several times

to avoid growth of unwanted mould as well as to obtain the desired smoke colour and flavour. Once smoking is completed, drying takes place at 12–15 °C and an RH of 72–75% until 30% of weight is lost. After removal of the casing, the dried product is thinly sliced and commonly modified atmosphere packed.

#### **24.4 Black Forest ham (Germany)**

Black Forest ham is made from deboned pork legs with the topside as well as the hock (knuckle) removed. A heart-shaped piece of meat, including fat and skin, is salted in a very similar way to Parma coppa and placed in a tub for 2–3 weeks, with the meat being moved every week. The salted pieces of meat, containing nitrite, are then placed in layers in a press with sheets of stainless steel dividing each layer. The layers are then pressed under chilled conditions for around 2 weeks and strong pressure is applied in order to flatten the product as well as to help the removal of moisture by simply pressing out water from the meat, thus reducing subsequent drying time. During this period of intensive pressing, equalization of curing additives takes place as well. Once pressing is completed, the product is hung with two strings on smoking sticks and is treated in nearly the same way as Parma coppa; the only difference is that Black Forest ham is not placed into any type of netting or casing and smoke is heavily applied until an almost black colour is obtained. Finally, drying takes place at 12–15 °C and an RH of 72–75% until 30% of weight is lost. The dried product is often thinly sliced and modified atmosphere packed but is also commonly sold as a whole piece and sliced upon sale.

#### **24.5 Serano ham (Spain)**

Certain quality criteria have to be followed in the production of Serano ham; the pig to be processed must be a cross-breed of Landrace and Duroc and the pigs must be between 9 and 12 months old before they are slaughtered. The pigs to be utilized for Serano ham should be bred and slaughtered in Spain and no supplementary protein or mineral feed can be given to the pigs during the fattening process. Acorns are fed to the animals, however, which has an impact on the chemical make-up of their fat, thus creating a distinctive flavour during drying as a result of lipolysis. The legs to be salted have to weigh at least 6.5 kg and only coarse sea salt can be applied during salting; no other additive or spice can be applied at this stage and nitrate is the only other permitted additive in the manufacture of Serano ham. Drying has to last in total at least 9 months but 1 year is the general norm. The process is very similar to Parma ham and entire pork legs, including hock (knuckle)

and trotter, are salted, using around 30–35 g of salt per kilogram of leg. The salted product is stored under chilled conditions at 1–5 °C for around 3 weeks and an RH of 80–85% before a second load of salt is applied. The salted product is then stored for another 2 months for the equalization of salt under chilled conditions and during this stage the  $A_w$  is reduced to 0.95 in all areas of the salted leg. Once equalization is completed, the product is dried at 12–15 °C and an RH of 70–74% for another 6–12 months until around 33–35% in weight are lost. Serano ham is not smoked.

## 24.6 Biltong (South Arica)

African biltong is made from strips of salted meat. Beef is still the meat of choice, but game meats such as springbok are processed more often nowadays. The finest-quality biltong is garing-biltong, produced from the eye muscle from the loin (*Musculus longissimus dorsi*) and the most tender product is binne-biltong or oumase-biltong, which uses fillet meat. To make all types of biltong, lean muscle tissue is utilized as the possibility that rancidity develops during the months of drying is reduced when lean meat is used. In addition, meat from younger animals is preferred as this meat contains less intramuscular connective tissue than meat from older animals. During trimming as much connective tissue as possible is removed and lean pieces of meat are cut into strips of around 30–50 mm in width.

The thickness of the strips is a matter of personal choice and, in more humid areas, thinner slices are used. The meat is salted, at a level of around 35–40 g per kilogram of meat. In the past, only salt was added to the meat, but nowadays spices are commonly added, as well as brown sugar. Spices such as aniseed, coriander, garlic and allspice are commonly added, but at levels where they do not overpower the meat flavour itself. Bicarbonate of soda is used to prevent mould growth in biltong manufactured in more humid areas and is applied at a level of around 0.6–0.8 g per kilogram of meat. In addition, potassium sorbate at 0.05–0.1% is occasionally used as well as nitrite and nitrate, with nitrite being more often used as nitrate. The salted pieces of meat are placed in tubs under chilled conditions and left standing for several days, with the pieces of meat occasionally being shifted around. Once removed from the tub and when equalization of salt is completed, the salted pieces of meat are then dried until around 50% of weight is lost. As a result of such heavy drying, the level of salt increases within the product to around 6–7% and the  $A_w$  is reduced to levels between 0.7 and 0.75. The bacteria count on biltong varies somewhat and values between  $10^4$  and  $10^6$  per gram of product are commonly seen, made up predominantly from *Lactobacillus* spp. and *Micrococcus* spp. Products which have been treated with preservatives such as sorbate exhibit a bacteria count around  $10^2$ – $10^3$  per gram of product. Mould can be a problem and, in particular, *Aspergillus glaucus* is frequently seen on the product. Biltong should always be eaten at

room temperature for optimal flavour development and the product is generally not smoked.

### **24.7 Pastirma (Turkey)**

Pastirma is a salted dried beef product made in Moslem countries. Hindquarter meat is cut into strips 40–50 cm long at a thickness (diameter) of between 4 and 5 cm. The meat is covered with salt which contains 0.02–0.03% potassium nitrate and is stored in piles for 1–2 days at room temperature. The cut strips of meat also commonly have been incised to facilitate the penetration of salt into meat. After 1–2 days, the pile of salted meat is turned over, salt is applied once again and left for another day. The salted meat is washed briefly and then heavily pressed for around 12–24 h. After pressing, the meat is dried for up to 2 weeks before a paste called *cemen* is applied to the semidried meat with a thickness between 4 and 6 mm. The paste consists of around 35–40% garlic, spices such as hot paprika, kammon, mustard and other powdered materials as well as water, but the water content of the paste is only around 30%. Garlic is by far the most important part of the paste, not only because it imparts a strong flavour to the product, but also because it prevents growth of mould on the product. Further drying takes place, reducing the  $A_w$  to around 0.85 until salt is present in the finished product at a level of around 5.5–6.0%. The level of moisture in the dried product is around 30–32%. Mould is hardly ever seen on this product as the high concentration of garlic effectively inhibits growth of mould on the surface of the meat. The garlic present within the paste demonstrates fungistatic properties for a number of months but, in pastirma dried for a long time, the effect of the garlic is gradually lost as the fungistatic substances are volatile. In addition, lactic acid bacteria are found on pastirma in high numbers (up to  $10^6$ – $10^7$  per gram of product) which reduce the pH value to around 5.4–5.5, thus introducing a hurdle against growth of Enterobacteriaceae.

### **24.8 Bündner fleisch (dried beef ‘bündner style’) (Switzerland)**

Bündner fleisch is a dry-salted beef product made by processing meat from young animals (2–2.5 years old). Meat from young animals is used because the intramuscular fat must be white rather than yellowish in colour and the meat must have little marbling as a dark-red-coloured finished product is desired. The animals are fed dried grass for 4 months prior to slaughter in order to reduce the  $A_w$  in the meat itself and to obtain the desired dark-red colour. To produce this product, cuts of meat from the hind leg are well trimmed so that they do not exhibit any connective tissue or surface fat. The

pieces of meat are commonly cut into rectangular or even slightly square pieces of 2.5–3.5 kg weight. Curing additives such as salt (23–25 g per kilogram of product), nitrate (0.4–0.5 g per kilogram of product) as well as spices such as garlic, pepper and crushed bay leaves are applied. Nowadays, a mix of nitrite and nitrate is commonly used to speed up the development of curing colour as well as to introduce a hurdle against bacterial growth right from the start. The salted pieces of meat are neatly placed in a container and brine collects on the bottom of the container within a few days. The salted pieces of meat are shifted around several times within the salting period, which lasts between 3 and 4 weeks and takes place at temperatures between 3 and 5 °C. Pieces of salted meat are then placed into nettings or tightly filled into fibrous casings. The product is then commonly left for another 1–2 weeks under chilled conditions for the equalization of curing additives. During this time of equalization the product is placed in layers separated by sheets of metal in a press to remove water effectively. Afterwards, the stabilized product is placed for around 3 months at a temperature of 10–14 °C and an RH of 70–75% for drying. During the period of drying, the product is placed several times into the press for 1–2 days to speed up drying as pressing forces moisture to penetrate to the surface, from where it is more effectively removed during subsequent periods of drying. Bündner fleisch is traditionally not smoked but a slight application of smoke occasionally takes place to minimize the risk of mould during drying. The loss in weight during drying is between 40% and 45% and the product is fully stabilized through its low  $A_w$ .

## 24.9 Beef jerky (USA)

Beef jerky originates from the dried meats prepared by native Americans to suit their nomadic lifestyle. Later, cowboys adopted this type of food as they could store it in their saddlebags. The word ‘jerky’ as such originates from the fact that cowboys hand cut or pulled (jerked) meat from a side of beef. Beef jerky is produced from very lean muscle tissue from the hind leg such as topside meat or inside or outside rounds. No connective tissue or fat should be present in the meat and, as a result, a product very low in fat is obtained. To produce beef jerky, extremely well-trimmed meat is sliced into slices 4–8 mm thick, weighed and subsequently mixed with a marinade containing salt, nitrite, ascorbate (erythorbate), sugar, spices (garlic, onion, chilli and cayenne pepper) and quite commonly materials such as red wine, soy sauce or Worcestershire sauce as well. The meat is left to marinade for 12–14 hours under chilled conditions before being placed on grid racks or hung up. Several different methods of drying are followed. One method is to dry the meat at 60–65 °C and at a low RH until an  $A_w$  below 0.89 is obtained, with no smoking taking place. Drying of food takes place at a fast rate at temperatures of around 60–65 °C because temperatures above this range

more or less cook muscle tissue, thus entrapping moisture. Another method is to dry the laid, or hung, marinated slices of meat and then to smoke them with hickory or maple at 60–70 °C until the desired smoke intensity is obtained. Further drying then takes place at the same temperature until an  $A_w$  below 0.89 is obtained. Yet another method is to apply hot smoke right from the beginning at 60–70 °C until an  $A_w$  below 0.89 is obtained, which results in a strongly smoked product. Occasionally, the marinated meat is also first heated with dry heat to 70 °C to kill pathogens before subsequent drying at 60–64 °C to reduce the  $A_w$  to levels around 0.86. Such treatment makes the product doubly safe as possible pathogens are destroyed via cooking initially before an  $A_w$  of around 0.86 stabilizes the product once more. At an  $A_w$  below 0.89, bacteria such as Enterobacteriaceae as well as *Staph. aureus* are well controlled. Most frequently, an  $A_w$  of 0.86 or less is aimed for so that the product is very safe with regard to microbiological spoilage and so that a shelf-stable product is obtained, which does not require refrigeration. In order to achieve a consistent reduction in  $A_w$  within all slices of meat, the meat has to be sliced to a consistent thickness. Thicker slices, which would be underdried slices compared with thinner slices, would not experience the desired drop in  $A_w$  and the product would not be microbiologically stable. The low  $A_w$  values not only are the result of drying, or loss of moisture as such, but also are due to the high level of salt as well as, occasionally, the sugar present, causing the reduction in the  $A_w$  within the product itself. The dried product is commonly vacuum packed which eliminates growth of mould as well as being modified atmosphere packed. A modified-atmosphere-packed product contains around 20–30% carbon dioxide as well as 70–80% nitrogen. Generally, beef jerky displays an  $A_w$  of 0.86 or less, a level of moisture of around 23–25%, a level of salt of around 4.0–4.5% and nitrite is added according to the relevant food standards, frequently at a level of between 150 and 200 ppm per kilogram of marinated meat.

#### **24.10 Rou gan and shafu (PR China)**

Dried meat products (sou gan) are produced in China in many different ways. Rou gan is the most common product and this product has been produced in the same way for many years. This product is visually not very attractive and has a crumbly structure. It is also dark in colour and occasionally sold in shredded form. Rou gan and similar products are heavily dried and demonstrate an  $A_w$  below 0.70. To produce rou gan, lean meat from the loin or leg is cut into thin slices of around 2–3 mm thickness and then marinated in a mixture of sugar, salt and spices such as five-spice mix (watchau (Szechwan pepper), anise, clove, cinnamon and fennel), MSG and soy sauce. The sliced meat is marinated in this mixture for around 24–36 h at room temperature and then dried on racks at around 60 °C until around 45–50% of their original weight is lost. The slices are then grilled over coal at around 150 °C

for a few minutes and subsequently dried by room temperature until an  $A_w$  below 0.70 is reached. Some products even demonstrate an  $A_w$  below 0.60. These products are very dry in texture and sweet in taste as between 8% and 10% of sugar is present in the finished product. The level of salt is around 2.5%. A visually improved version of rou gan is shafu, which is sold in a sliced form with an  $A_w$  of around 0.78–0.80. Since the  $A_w$  is higher, shafu is juicier than rou gan. It is also strongly red in colour (but not as dark as rou gan), soft in texture and less sweet than rou gan.

## 25

# Spreadable liver sausage and liver pâté

Liver sausage and liver pâté are products manufactured all over the world and their acceptability among consumers varies considerably. Whilst liver sausages and pâtés in some countries form part of the everyday diet, in other places they are eaten by only a few consumers. The variety of products available is endless because all possible spices and herbs as well as other materials such as wine, port and brandy are used as flavouring materials. Whilst liver sausages are generally filled into casings, liver pâté is primarily filled into some sort of mould. As the name indicates, liver is commonly incorporated into these products whilst other types of pâté consist of meat and fat material only. Most commonly, the meat and fat material used in the manufacture of liver sausage and pâté is precooked and the raw liver acts as an emulsifier. During manufacture of liver pâté and sausage, a true emulsion is formed, as there are hot and liquid water as well as mostly hot and liquid fat in the sausage mass and therefore both phases, the fat and the water, are present in their liquid form. Liver sausages and pâté are generally cured products and nitrite is added. However, some old-fashioned products, commonly produced on a small scale, are made without nitrite. Liver sausage and pâté are generally consumed in a cold state together with bread and are an excellent way of adding value to low-value materials as the materials processed are mostly fatty trimmings and liver.

### 25.1 Selection and preparation of raw materials

Liver sausages and pâté are generally produced from pork but chicken or beef can be processed without any problems as well. As with all meat products,

a low bacteria count in the raw materials is desirable and between  $10^2$  and  $10^4$  per gram of product is the optimum. Most of the raw materials utilized, such as pork head meat (PHM), jowls (cheeks), fat, liver and skin are highly perishable and some of these quickly show a high bacteria count if they are not treated or stored properly. Spores from bacteria such as *Bacillus* spp. and *Clostridium* spp. are also often present on these materials. Some would argue that the bacteria count of meat and fat material to be processed is not of importance as the meat and fat materials are precooked anyway before being further processed into liver sausage. Even though this statement is correct as such, it is simply never of advantage to work with raw materials with a high bacteria count. A large number of bacteria have a negative impact within the finished product on parameters such as flavour, colour development and colour stability, which cannot be rectified through subsequent cooking.

It is not directly a disadvantage to use PSE or DFD meat (see Chapter 4, Section 4.1) as the meat and fat materials are precooked before being further processed. Cooked, and therefore denatured, muscular protein is not functional any longer and is not able to immobilize water or to emulsify fat during further processing. The unfolding of the cooked (denatured) protein, or change in its three-dimensional structure, also changes the configuration of the lipophilic as well as hydrophilic groups within the protein molecule and it loses its ability to act an emulsifier. The disadvantage in processing PSE pork, however, is that there is an increased cooking loss during precooking if the material is processed by the impact of steam, or in a hot-water bath, rather than in a cooking bowl cutter. Increased levels of hot broth have to be added afterwards to the sausage mass to compensate for the increased loss in weight during precooking; otherwise a dry product with reduced spreadability would be obtained. Having insufficient water within the product in relation to the fat content also destabilizes the emulsion itself as a high percentage of hydrophilic groups within liver protein are not utilized. Broth is a very economical (low-cost) material, so it should be fully utilized. Adding an insufficient quantity of broth to the sausage mass, on the other hand, increases the cost of the overall recipe significantly. DFD meat, because of its enhanced WHC, reduces the cooking loss during precooking and less broth has to be added subsequently to the sausage mass as per standard. Having said that, it is very unlikely that all pork or beef processed for a batch of liver sausage would demonstrate either PSE character or DFD character. When producing liver sausage using beef, or pork, the meat and fat materials processed are commonly a mix of materials originating from several different animals. Therefore the degree of significantly enhanced (or decreased) cooking losses obtained owing to the presence of DFD or PSE meat during cooking compared with the standard is quite small and also unlikely to cause a problem.

Liver sausages commonly exhibit a fat content between 25% and 40% and therefore cannot be said to be 'low in fat'. Liver is added for its impact on taste, for the emulsification of fat and water and to stabilize the sausage

mass overall. The texture of a liver sausage is largely determined by solidified fat, which is covered in a protein matrix made from solubilized liver protein as well as gelatin, obtained from the connective tissue present in meat and fat material which changed from collagen into gelatin during thermal treatment. Therefore, the level of fat in a liver sausage regulates texture and spreadability to a large degree. Solubilized liver protein is a natural emulsifier, creating a three-dimensional matrix upon cooking which starts to denature at temperatures above 60 °C. This three-dimensional matrix inhibits the unification of fat particles, therefore stabilizing the emulsion. The protein matrix consists of strings of protein and an enhanced level of protein forms a thicker layer around droplets of fat and water, thus increasing the stability of the emulsion. On the impact of pressure during spreading of the liver sausage on to bread, the protein matrix breaks easily as it is very brittle. This gives the product good spreadability.

When pork is utilized for the production of liver sausage, all types of fat can be processed and no significant difference will be seen in the final product by processing fat from different cuts of a pig. As fat originating from loin and neck is the preferred choice for the production of salami and emulsified sausages, fat from shoulder and legs (or in combination with loin and neck fat) can be usefully employed for the manufacture of liver sausage. In general, the type of fat processed in liver sausage is of insignificant importance as long as the desired fat content within the final product is obtained and therefore fatty pork belly is another commonly processed raw material for liver sausages. Finally, jowls (cheeks) are also a highly valuable raw material and are frequently processed with the skin on. All these materials contain a high degree of unsaturated fatty acids which contribute positively to spreadability in the finished product. There is high level of connective tissue and therefore collagen within these materials, which turns into gelatin during heat treatment.

Generally, fatty pork bellies have around 45–55% fat, jowls around 60–70% fat, PHM around 25–40% fat, back fat around 80–90% fat, fat from leg or shoulder around 80–85% fat and kidney fat around 90% fat. A level of fat between 20% and 40% can be present within liver sausage without the risk of fat separation when the amount of liver within the product is around 25–30% as well. The water in low-fat liver sausages tends to separate during thermal treatment and, to avoid water separation, the amount of liver should be lowered to around 15–20% in these products. Higher levels of meat should be utilized to compensate for the reduced levels of liver.

On the other hand, the amount of liver should be increased and less lean meat is utilized when a small amount of liver is processed in the first place. Separation of fat during thermal treatment can be seen at a level of fat of only 25–30% if insufficient liver is introduced. This problem can be solved by increasing the level of liver and applying less meat at the same time. As stated above, levels of fat of around 35–40% can be easily processed without seeing fat separation if liver is applied at the same time at levels of between

25% and 30%. Retorted liver products frequently exhibit water separation when the level of fat is between 15% and 20% only. To rectify the problem, the level of fat can be increased to 25–30% or less liver is applied if the level of fat has to remain the same and, at the same time, more meat should be introduced. In retorted products, the level of fat should not exceed 30–32% as a stable product cannot be produced with fat levels above 32% and around 25–30% liver is required to stabilize around 30% of fat in retorted products. If fat separation is observed in retorted products, the level of fat should be reduced and elevated levels of liver, and especially meat, should be applied. Increased levels of liver solve the problem of fat separation when the level of fat has to remain unchanged. However, the level of liver applied in retorted products is restricted owing to sensory constraints as high levels of liver impart a burned taste mainly because of the high level of sugar (glycogen) naturally present in liver as the Maillard reaction occurs during retorting to a significant degree. As a result, retorted liver sausage generally demonstrates a moderate level of fat around 25–28% and liver is applied between 18% and 22%.

Pork flare fat (kidney fat) and beef suet are hard to emulsify as they are highly saturated fats and so they are rarely processed. Lean meat and fat are most commonly not processed as separate materials in the production of liver sausage and fatty trimmings of meat are predominantly used instead. Another highly valuable material for the production of liver sausages is PHM as this material is high in fat, high in connective tissue and more flavoursome than other cuts of meat. PHM is also generally of low cost. After being cut into halves, pork heads are either soaked in brine for several days or injected with brine to speed up colour development (the treatment of pork head is described in more detail in Section 25.3). The pork head to be processed must not be slimy or display any off-flavour as this would have a negative impact on colour and flavour development within the product. The presence of connective tissue within meat and fat materials utilized for liver sausage is required as collagen, one of the main components of connective tissue; this turns during thermal treatment into gelatin, which contributes positively to spreadability and mouth feel in the finished product. Gelatin, in conjunction with elevated levels of fat, creates a very smooth and creamy mouth feel in the product. In addition, PHM is dark red in colour, thus supporting the formation of a strong curing colour in the finished product, it is very flavoursome and the skin connected to PHM contributes to spreadability in a very positive way. The level of fat within PHM is between 25% and 30%, although the important fact is that, whatever meat and fat materials are utilized for the production of liver sausage, the overall fat content should remain constant according to a set recipe. Variations in fat content are commonly the reason for faulty products, which is especially a problem in small batch sizes.

If fatty pork bellies are processed, the variation in fat content can be significant. The risk of obtaining fat separation in the product during thermal

treatment is reduced in large batch sizes as the overall fat content is more likely to be correct according to the standard recipe; even though one pork belly might be fattier than the standard, another might counterbalance this by being leaner. In small batch sizes such variations in fat level can be a real problem because greatly varying levels of fat are obtained in the finished product, either increasing the risk of fat separation or creating variations in mouth feel and consistency. Large processors of liver sausage analyse meat and fat materials to be processed prior to cooking in the bowl cutter to ensure a consistent level of fat in the finished product. A balanced level of fat is clearly essential for obtaining a stable emulsion and good spreadability of the product as well as the fact that fat is quite an inexpensive raw material. Low-fat products are commonly sandy and rough in texture because fat and connective tissue are simply missing within the product.

Cooked pork skin is a frequently utilized material as it is inexpensive and helps to obtain good spreadability in the finished product. Generally, recipes contain between 5% and 10% of pork skin when no skin-containing material, such as PHM, is processed. Collagen present in skin turns into gelatin, which covers droplets of water within the emulsion and therefore acts as a stabilizer against water separation. In liver sausages of high quality, however, PHM and skin are generally not utilized despite their positive impact regarding flavour, texture and mouth feel. Connective tissue, present in liver sausage between 2% and 4% in the final product, contributes very positively towards mouth feel and spreadability. Levels above that, however, create a gummy texture and spreadability is lost at the same time. Lack of connective tissue and therefore gelatin causes a sandy rough mouth feel whilst excess levels increase firmness of the product thus reducing spreadability.

The liver is generally processed raw because activated liver protein acts as an emulsifier in the product, holding hot liquid fat and water together during pasteurization. The activated liver protein prevents fat and water separation by forming a three-dimensional matrix which encapsulates droplets of fat and water. The amount of liver incorporated within the final product is generally between 25% and 30% and fresh or chilled liver provides a more typical, fresh and clean liver taste than frozen liver. During freezing of liver, as during freezing of meat, water present within liver tissue turns into ice and crystals of ice damage capillaries through which gall liquid was previously pumped. As capillaries are damaged by the impact of ice crystals, traces of gall liquid penetrate into liver tissue, which can cause a light bitter off-flavour in the finished product. The gall itself has to be removed from the liver in any case because gall liquid imparts a strong bitter taste and would certainly be detected in the finished product. Pork, veal and chicken liver all give a clean and pleasant taste of liver whilst use of beef liver frequently results in a slight bitter taste, especially if levels in excess of 30% are present within the recipe of the product. The age of an animal largely determines the impact on flavour and the fact that liver originating from beef is commonly significantly older than, for example, liver coming from pork explains the

unfavourable impact of older liver tissue. The liver is the cleaning organ within an animal and thousands of litres of blood are filtered through the liver every day. Materials such as heavy-metal ions (copper and iron) accumulate over time and increase the negative impact on taste. Liver tissue from old animals are commonly dark and of brown–black colour. This dark colour has an impact on the overall colour of a liver sausage because around 25–30% of the product is made from liver.

Liver tissue contains a high degree of free water as well as blood and is therefore highly susceptible to spoilage. Proper hygienic handling and permanent storage at temperatures below 4 °C ensures a microbiologically sound raw material for 3–4 days. Liver protein contains bipolar groups, lipophilic as well as hydrophilic, which act as emulsifiers and solubilized liver protein fully or partly covers particles of fat. The major proteins found in liver are albumin, globulin, glycoprotein as well as collagen, with collagen being present at around 1%. The opinion that liver has to be blanched before use cannot be supported technologically. If blanching is required to improve the microbiological status of liver, then the liver should not be utilized in the first place. Also, every degree of blanching denatures proteins and less functional protein will be subsequently available for emulsifying fat and water. There is no difference between warm liver (straight from the carcass after slaughter), chilled liver or frozen liver with regard to the ability to act as an emulsifier. From a taste point of view, warm liver gives the strongest and most pleasant liver taste. The pH value of liver after slaughter is 7.2 and drops afterwards to around 6.4. As a result of such a high final pH value, the shelf life of liver is reduced if not handled properly and this is also due to the high content of free water within liver tissue itself. The bacteria count of chilled liver is between  $10^2$  and  $10^4$  per square centimetre and bacteria such as *Streptococcus* spp., *Staphylococcus* spp. and *Micrococcus* spp. are mainly present. If less than 10% of liver in a recipe is used, this generally causes a problem as a very thin layer of solubilized protein covers finely cut fat particles, thus increasing the risk of fat separation during thermal treatment. The level of glycogen in liver tissue can be above 8% but is on average 1.5% in liver from beef and around 0.4% in liver from pigs. Some manufacturers of liver sausage and pâté make the effort to process warm materials, especially if a slaughterhouse is part of the factory. Warm meat, as well as warm liver, mostly utilized from pigs is processed straight away in the cooking bowl cutter and this has a very positive impact on the flavour of the finished product.

Liver sausages can be produced with oil instead of utilizing fat. Oil is used in products such as beef or chicken liver sausage, where no pork fat can be utilized. However, beef and chicken liver sausage can be produced with beef or chicken fat as well but, for marketing purposes, the combination of lean meat and oil gives the product a superior status. Prewarming of oil is not required as oil remains liquid at room temperature and can be kept emulsified well prior to pasteurization of the product. This is in comparison with pork

or any other solid fat, which turns from liquid into the solid state at temperatures below 35 °C, thus reducing the stability of the emulsion significantly.

## 25.2 Selection of additives

The variety and amount of additives introduced into liver sausages vary significantly. Salt is added to all products, however. Liver sausages are usually mildly salted and the level of salt is generally between 12 and 18 g per kilogram of product. Salt's only function in the sausage is its contribution to taste and flavour. The presence of salt reduces  $A_w$  value of the liver sausage but this is not of significance with regard to parameters such as shelf life as liver sausage has a high water activity by nature. Liver protein is water soluble and no salt is required to activate or solubilize it. Equally the myofibrillar proteins (myosin and actin) in precooked meat are no longer functional; so, liver sausages can be produced without the addition of any salt. Although the manufacture of low-salt or even salt-free liver sausages is not a problem in terms of technology, a salt-free product would not be acceptable from a taste perspective.

Nitrite (see Chapter 7, Section 7.2) is predominantly added for its contribution to development of curing colour and curing flavour. Nitrite has some impact on shelf life, so it should be present in the cooked product at the highest permitted level. However, nitrite's impact on shelf life should not be overrated. Proper thermal treatment during pasteurization and correct storage of the product plays a more critical role in extending shelf life than the level of nitrite in the product.

Liver tissue contains a large amount of haemoglobin which is turned into nitrosohaemoglobin by the presence of nitric oxide (NO) and this affects the colour of the finished product. For faster and more effective colour development, as well as to stabilize the curing colour in the cooked product, materials such as ascorbic acid or erythorbate are introduced at levels around 0.5–0.7 g per kilogram of total mass. Ascorbic acid should not be added at levels above 0.7 g per kilogram of total mass. In addition, as is the case when processing other cured meat products, ascorbic acid must not come in touch directly with nitrite as the toxic gases NO and nitrogen dioxide (NO<sub>2</sub>) would be obtained immediately, with nitrite being lost resulting in poor, or no, curing colour.

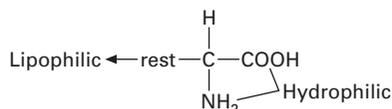
Spices and herbs are added according to taste. A wide variety of liver sausages of different flavours can also be produced by adding substances such as port and brandy. Traditional-style non-cured liver sausages and pâtés are usually made without nitrite but occasionally nitrite is accidentally introduced when spices, such as marjoram, containing nitrate, are added. Water containing nitrate can also be the cause for the formation of unwanted curing colour in non-cured products as parts of nitrate introduced are reduced to nitrite, resulting in the formation of some nitrosomyoglobin or

nitrosohaemoglobin. Fresh onions are not used in retorted products owing to their high glycogen content and occasionally high bacteria count. The glycogen content in onions combined with the glycogen present in liver could create a sour taste in the finished product. Onion powder or oleoresin is microbiologically much safer. In pasteurized products, fresh onions are frequently used.

Phosphates are not introduced into liver sausages because all the muscular protein in the meat has been denatured during precooking before the sausage emulsion is produced.

Emulsifiers such as monoglyceride and diglyceride of fatty acids and others (see Chapter 6, Section 6.17) are frequently introduced into liver sausage to reduce the risk of fat separation during thermal processing. Monoglycerides have stronger hydrophilic tendencies than diglycerides which are more lipophilic. These emulsifiers do not create a three-dimensional matrix as is seen in solubilized liver protein. Emulsifier molecules have hydrophilic and lipophilic ends. The hydrophilic end orients itself towards the water phase within the emulsion whilst the lipophilic end penetrates into the fat phase. As a result, the surface tension between the two immiscible phases (fat and water) is reduced, which increases the stability of the emulsion. The quantity of emulsifier used depends on the product but is in general 3–5 g per kilogram of sausage mass. Other ingredients, such as sugars, are commonly mixed with the emulsifying agent. Esterified emulsifiers such as monoglyceride containing around 25% citric acid seem to reduce the risk of fat separation in pasteurized products but may increase the risk of fat separation in retorted products.

Natural emulsifiers such as caseinate, egg protein and blood plasma also stabilize an emulsion as there are hydrophilic and lipophilic parts in their amino acids. Only egg protein forms a matrix as liver protein does, however. Caseinate (see Chapter 6, Section 6.1.1), in contrast, covers the particles of fat and firmly holds them during heat treatment. Materials such as sodium caseinate are regularly applied to retorted liver sausages and pâtés as the ability of sodium caseinate to emulsify and stabilize fat is enhanced at high temperatures. Other proteins, such as soy, can also be used as emulsifiers in liver sausages. The carboxyl group (COOH) and the amino group (NH<sub>2</sub>) are the hydrophilic (water-loving) part of protein-based emulsifiers, whereas the rest of the amino acid chain is the lipophilic (fat-loving) part. The lipophilic character of an amino acid is based on its chain length and longer molecules are more strongly lipophilic. Liver protein has a larger number of highly hydrophilic groups and is an excellent emulsifier of fat-in-water emulsions. Generally, when fat levels are high compared with water levels in a liver sausage, the risk of fat separation increases. When there are high levels of water but little fat present (i.e. in a low-fat product), water separation frequently occurs during thermal treatment of the product. Figure 25.1 demonstrates the emulsifying capacity of proteins which have lipophilic as well as hydrophilic parts within their molecule.



**Fig. 25.1** Lipophilic and hydrophilic components in a protein molecule.

Milk, or sweet cream, is commonly applied to liver sausage in order to increase the smoothness and taste of the product. Other types of sugar such as dextrose and sucrose are added at around 5 g per kilogram of sausage mass to cover up the salty taste. Vanilla, or vanillin, is often added to finely cut liver sausage as it adds a pleasant sweet taste to the product. Starch is occasionally introduced but does not aid emulsification, as starch cannot prevent an unstable emulsion from separating during pasteurization. This is because starch lacks both lipophilic and hydrophilic groups within the molecule. Starch does immobilize water during pasteurization (gelatinization of starch), however, which supports the stability of an emulsion. Gelatin (see Chapter 6, Section 6.1.8) is occasionally introduced to increase smoothness of the product as well as to support immobilization of water within the emulsion during thermal treatment.

### 25.3 Manufacturing technology using precooked hot materials (conventional method)

In the conventional method of producing liver sausages, all precured meat and fat materials are precooked in steam or a bath of hot water. Fatty meat trimmings, fatty pork bellies, jowls and other meat-containing materials are precured with nitrite (around 150–250 ppm per kilogram of product) and salt (14–18 g per kilogram of product). The materials are then well mixed and placed in the chiller for 12–24 h. This is to develop the curing colour before the materials are cooked. If pure fat is used as a raw material, precuring of fat is omitted as no myoglobin is present for the development of curing colour and the fat is cooked without being precured. Once curing colour is developed, all the materials are placed on racks, on trolleys or in nettings and thermally treated with steam or in a hot-water bath at around 85–90 °C until they are fully cooked and exhibit a temperature of 70 °C in the core. Precured meat and fat material should reach a core temperature of at least 68 °C during precooking as temperatures below that greatly increase the risk of fat and water separation during thermal treatment of the finished emulsion.

Another more rapid method of precuring and precooking materials at the same time is to place all materials to be precooked into brine containing salt and nitrite. The level of salt should be around 8–10% and nitrite around 400 ppm/l. The uncured materials, which must not be too large, are subsequently

cooked within this brine and both processes, curing and cooking, take place at the same time. If the pieces of meat are too large, cooking (denaturation of protein) will take place faster than the curing process and grey-green areas will occur in the core of the larger cooked pieces of meat. Generally, if meat and fat materials are precooked with steam or in a water bath, curing colour has to be fully developed prior to thermal treatment. As stated earlier, PHM is a perfect material for liver sausages and heads are normally cut into halves and cured whilst the bones are still in. Curing can take place in two ways. The first method is to place the heads into curing brine for several days under chilled conditions. Such a curing brine contains around 10–14% salt as well as around 1000–1300 ppm of nitrite per litre. All meat becomes perfectly cured and a strong curing colour is obtained. Before being placed in curing brine, all remaining hairs are removed with a flame treatment and the ears and eyes are removed as well.

Another method of precuring pork heads is by the injection of brine, which shows similar concentrations of salt and nitrite as the soaking curing brine. Only around 10–15% of the brine is injected just to incorporate salt at around 2% as well as sufficient nitrite for the development of a strong curing colour and flavour. Injected heads are then soaked in a light cover brine, with around 3–4% salt and around 200–300 ppm of nitrite at a temperature below 4 °C. The advantage of injection is that injected heads can be cooked after 24–36 h and a strong curing colour will be present in all areas. If soaking pork heads in curing brine only, at a maximum of 4 °C for microbiological reasons, at least 4–5 days are needed before all meat on the head is properly cured. The cured pork heads are subsequently cooked with steam at a temperature of 85–90 °C until cooked and all meat and fat material can be removed from the bones by hand. Any cartilage, or grizzle, must then be removed from the meat as well. Cooking of the cured pork heads can also take place in a hot bath with a water temperature of around 85–90 °C. Cooked and boneless PHM is generally placed in trays and stored frozen for further use unless it is to be used for liver sausage on the same day. Another option for short-term storage of boneless cooked PHM is to place it in an icy cold brine which contains a small degree of salt. Meat and fat may be stored like this for 1–2 days before being further processed. Pork skin is frequently precooked separately from fatty meat trimmings as a longer cooking time is required to obtain soft cooked pork skin. Skin is adequately cooked so that it yields easily to a slight degree of pressure only. Skin should not be overcooked so that it falls apart but equally, if it is undercooked, it will exhibit a hard texture once thermally treated and cannot be cut to a degree so as not to be seen in the finely cut emulsion.

Another option for obtaining precooked materials for liver sausage is using cooked PHM and precooking fat (which has not been precured) and pork skin separately in steam or hot water as described above. Fully cooked PHM is placed in hot water for a while to raise its temperature. The combination of freshly cooked fat and skin and reheated meat from pork head results in

a perfect combination for further processing. Pork skin and the skin present on PHM are very rich in collagen. During both the precooking and the final cooking stages of the liver sausage (pâté), collagen first shrinks under the impact of the heat, at a temperature of around 60–65 °C. Next, continuous heating raises the temperatures to between 65 and 85 °C which produces a softening effect on collagen, depending on the age of the animal, but no individual molecule of tropocollagen is obtained yet. Collagen is still insoluble but is already of a gummy texture. Finally, further heat treatment causes collagen to take water up and the swelling collagen molecule leads to an increase in volume as well as softening of the molecule. At the end of this process, cross-links within the molecule are broken down and the collagen becomes soluble. Gelatin is formed, producing a gel upon cooling. If the application of heat is continuous or too long, tropocollagen turns into individual strands of procollagen, which does not form a gel upon cooling (see Chapter 1, Section 1.3). The aim of cooking is to convert most of the collagen into gelatin but inevitably some collagen always remains as undissolved collagen whilst a small percentage turns into procollagen.

The liver is often precut on its own in the bowl cutter at a high knife speed until bubbles can be seen within the finely chopped liver mass. Upon bubbling, the knife speed is slowed down, salt and nitrite are added and the whole mixture is gently mixed for a short while. This produces a highly tacky mass of finely cut liver. This separate additional processing step activates the liver protein and can be omitted if a bowl cutter able to generate a high knife speed is available because, as mentioned earlier, liver protein is water soluble and no salt is needed to activate protein from liver. Precutting of liver merely serves the purpose of obtaining a larger surface so that emulsification of fat and water takes place more effectively. However, precutting of liver is still often traditionally carried out because it has the advantage that already finely cut liver, when added to finely cut meat and fat materials, does not need to be cut for much longer. Large processors of liver sausage and pâté, working with sophisticated and high-speed bowl cutters, often omit precutting of liver as it saves an additional processing step and therefore time. Before production of the first batch of the liver sausage using precooked meat and fat materials the bowl cutter has to be prewarmed by placing some hot water into it which is removed shortly before the first batch is produced. Neglecting this warm-up means that the heat of the materials to be processed is absorbed by the cold bowl which increases the risk of fat separation during the emulsification process.

Whichever way that the meat and fat are precooked, all the freshly cooked and hot or reheated materials (PHM) as well as cooked skin are placed in the prewarmed bowl cutter and cutting commences. The weight which was lost during the precooking of the meat and fat materials is added back as hot broth into the bowl cutter and, as a rule of thumb, the weight of precooked materials at this stage roughly equals the weight prior to precooking. Practical experience shows that the amount of broth added to the bowl cutter can even

be slightly more than that lost during precooking. During the initial stages of high-knife-speed cutting, the emulsifier is added, usually dissolved in broth first. The high-knife-speed cutting serves no other purpose than that of obtaining finely cut particles. No activation of protein occurs during the cutting as all proteins were denatured during cooking. Knives rotating at around 3500–5000 rev/min during comminution result in finely cut particles of meat and fat. This process requires a time of around 5–7 min and, once completed, liver is added to the mass. When the liver is added, the temperature of the finely cut meat and fat materials should be at or below 60 °C. Temperatures above 60 °C denature the liver protein which is needed for the emulsification of fat and water. This is particularly important if the sausage contains low levels of liver. A method commonly used to reduce the temperature to below 60 °C is to add a tiny amount of ice during cutting of the precooked meat and fat materials. The liver can be added at this stage, in which case cutting for another 3–5 min is required. Proper emulsification of the entire sausage mass will require longer if the liver is added uncut, because the liver tissue has to be cut before it can act as an emulsifier. The process of emulsification can be visually observed, as a very sloppy and watery mass of finely cut meat and fat materials turns into a smooth, creamy and often shiny homogeneous mix. Once the mass is properly emulsified, the knife speed is slowed down and all additives are gently mixed into the mass, with salt and nitrite being the last ingredients to be added. There is no fixed sequence regarding the addition of additives as protein activation is not a concern; however, salt and nitrite are the last to be added. Quite commonly, all additives including spices, herbs and colour enhancer are added prior to the addition of liver, and only salt and nitrite are added once the emulsion is created. If ascorbic acid is introduced to enhance colour, care must be taken that ascorbic acid and nitrite are not added to the sausage mass at the same time because those two materials react instantly with each other. The amount of salt and nitrite introduced in the final stages of the production process depends on the amount of salt that has already been added to the meat and fat materials during the precuring stage. For example, if the liver was precut separately and salt and nitrite were added to it, and all meat and fat materials were also precured before being cooked, then no salt is required any longer at the end of the emulsification process. Large-scale manufacturers of finely cut liver sausage and pâté do not precut liver to avoid this additional processing step and chilled uncut liver is added directly to the finely cut meat and fat materials even at temperatures above 60 °C. The amount of liver protein denatured as a result of having temperatures above 60 °C is compensated for by adding 2–3% more liver in the first place. Then the required amount of functional liver protein is present even though some protein is denatured.

Emulsifying is occasionally also achieved by mincing all precooked and hot meat and fat materials, as well as the raw liver, with a 4–6 mm blade and all minced materials are placed in a paddle mixer. Additives and spices are added and all is mixed well again before being passed through an emulsifier

or a colloid mill. Upon completion of the cutting or emulsifying process, the temperature of the finely cut liver sausage mass should be above 35 °C. A temperature above 35 °C within the emulsified sausage mass has the advantage that finely cut particles of fat are well dispersed and covered by solubilized liver protein so that the emulsion is stable at this stage. At temperatures below 35 °C, finely cut particles of fat unite and form larger particles of fat which are difficult to keep well dispersed and emulsified. As a result, the emulsion becomes more unstable at lower temperatures as large particles of fat cannot be emulsified properly and the risk of fat separation during thermal treatment is increased.

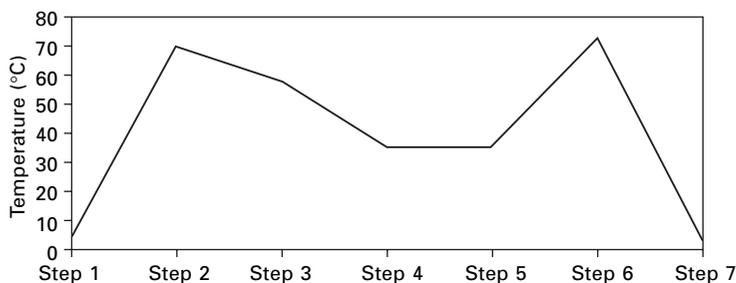
Added emulsifiers reduce surface tension between fat and water by keeping small particles of fat well dispersed in water for a prolonged period of time which, as a result, reduces the risk of fat separation during the subsequent cooking process. As a general rule, a bowl cutter should be at least 50% full to cut and emulsify effectively a fine liver sausage mass because smaller amounts of materials become 'lost' within the bowl cutter and emulsification becomes less effective. Hence, in order to produce liver sausage in a cost-effective manner, the bowl cutter is normally filled at around 90% which is cost effective as well as supporting proper emulsification. Small amounts of precooked and hot materials experience a drop in temperature much more quickly after the addition of liver than if the bowl cutter is full because a bowl cutter is often placed in rooms where the room temperature is quite cool.

A recipe for a finely cut liver sausage, not utilizing PHM, contains around 25–30% liver, 30–35% fat and 5% cooked skin, and the rest is meat. The desired level of meat and fat can also be obtained from a combination of fatty trimmings and jowls. Utilizing PHM changes the recipe in a way that less, or no, cooked skin is introduced because cooked PHM contains a fair amount of skin tissue in any case. Precooked fat is commonly processed with reheated PHM and such a recipe would show 25–30% liver, 20–25% fat and none or up to 5% cooked skin, and the rest is hot or reheated PHM. Precured and cooked jowls are also commonly utilized in conjunction with PHM, lean trimmings or fat, and possible combinations of such raw materials create generally a recipe containing around 25% liver, 30–35% fat and 5–10% skin, and the rest is lean meat. In products exhibiting a reduced fat content of around 15–20%, the amount of hot water, or broth, processed can be increased without water or fat separating as long as the amount of liver is around 25%. If reduced levels of liver are processed, the amount of added water, or broth, should be less. Levels of fat at around 30–35% may lead to fat separation if insufficient liver is used. Higher levels of liver and less meat within the recipe rectifies this problem while maintaining the same level of fat. A recipe consisting of around 35–40% fat should have a liver level of at least 25% to obtain a stable emulsion. If separation of fat occurs, the percentage of liver and/or meat can be increased by reducing the amount of fat. High levels of broth added to an emulsion high in fat supports separation of fat during

pasteurization as broth contains a fair amount of fat in itself. Retorted finely cut liver sausages are made up of around 16–18% liver and around 15–25% fat, with meat making up the rest. The reduced liver content is because of the increased risk that the Maillard reaction (see Chapter 4, Section 4.13) causes burning, or a burned taste, as the glycogen within the liver tissue reacts with protein in conjunction with high temperatures applied during the retorting process. In retorted products, levels of fat below 15% lead commonly to water separation and adding more fat is advised. If more fat cannot be added, the percentage of liver is reduced by adding more meat tissue.

The stability of a liver sausage emulsion depends, amongst other things, on the ratio of fat to water present within the product. Generally, as long as similar levels of fat and water are present as well as sufficient liver tissue to emulsify those two materials, the stability of the emulsion is high since hydrophilic and lipophilic groups of liver protein are equally utilized. This presents a problem in low-fat products as the amount of fat is significantly reduced whilst the broth, or water within the product, is not. Therefore, the amount of broth added back to the bowl cutter to compensate for the liquid lost during the precooking has to be lowered to maintain similar ratios of fat to water. Even with high levels of liver, very little fat commonly leads to water separation while levels of fat around 15–20% are generally very stable. Increased levels of fat stabilize the emulsion in low-fat products or the amount of liver can be reduced by lifting the meat content at the same time to avoid water separation in low-fat products. In low-fat products, the addition of gelatin or the utilization of materials rich in connective tissue (PHM and skin) helps to immobilize excess water to avoid water separation during cooking. Other parameters that have an impact on the stability of an emulsion are the temperature during emulsification (with higher temperatures supporting stability) and obtaining a small particle size because smaller particles of fat are more easily emulsified than larger particles of fat. If oil is utilized instead of fat within the finely cut liver sausage mass, the temperature is allowed to drop below 35 °C after being emulsified. This is because droplets of oil do not unite to form larger solid particles as oil remains liquid even at temperatures below 35 °C. However, a long period of time should be avoided between obtaining an emulsion produced with oil and thermal treatment (see Section 25.3.4).

Figure 25.2 illustrates a temperature regime during the manufacture of fine liver sausage. Cooking commences (step 1) and all materials are heated to around 70 °C (step 2); liver is added at a temperature below 60 °C (step 3); the temperature of the total mass drops after the addition of liver and emulsification occurs at 35 °C or above (step 4); the temperature should remain above 35 °C during filling until pasteurizing commences (step 5); pasteurization of the product occurs at a core temperature around 72–74 °C (step 6); the finished product is cooled and stored at 0–2 °C (step 7).



**Fig. 25.2** Temperature changes during the manufacture of fine liver sausage (see the text for an explanation of the steps).

### 25.3.1 Manufacturing technology using a cooking bowl cutter

The utilization of a cooking bowl cutter is a very efficient way of producing liver sausage as labour- and time-intensive processing steps such as precuring and precooking with steam, or in a hot-water bath, can be omitted. Untreated (raw) fatty meat and fat materials are placed in the bowl cutter and cutting starts on a medium–fast speed while salt and nitrite are added. Most types of cooking bowl cutter work via an indirect injection of steam which means that the bowl of the cutter is heated with saturated steam, the steam being introduced between the outside of the bowl and another layer of metal, which creates a double-jacket bowl. The steam heats the cutter bowl from the outside and the hot surface of the cutter bowl comes into contact with materials to be cooked inside the bowl cutter. This way steam is not directly applied to the materials to be cooked. As salt and nitrite were added right at the beginning of the cutting–cooking process, the three processes cutting, curing and cooking all take place at the same time in the hot bowl. The heat applied to the bowl during the initial phase of cooking should be at a moderate level as burning of protein could occur if the totally uncooked meat material is exposed to an extremely hot surface. The entire mass is subsequently heated to around 70–72 °C whilst being cut at a high knife speed. Also no cooking loss is obtained during the process. The mixture needs to be handled only once as the cooked materials do not need to be moved between cooking (with steam or in a bath of hot water) and cutting.

Cooking bowl cutters can also operate by direct injection meaning that steam is not injected into the double-jacket space between the bowl and metal liner but directly into the bowl instead, heating the raw materials to be precooked. In order to standardize the cooking process in a cooking bowl cutter, all parameters such as the speed of knives during cutting and cooking and the temperature of materials placed in the bowl cutter have to be constant in case the final temperature of the cooked meat and fat materials is established.

Placing materials in the bowl cutter which have a lower than normal temperature causes the cooking process to last longer, which means that materials will be overcooked, and also cut for too long. Overcooking results

in a higher amount of procollagen and the risk of water separation during pasteurization is increased. The product will also be less smooth as the amount of gelatin obtained is reduced owing to the increased level of procollagen which does not form a gel upon cooling. On the other hand, warmer than normal materials are cut less as the set final temperature, in most cases between 68 and 70 °C, is reached more quickly, thus causing undercooking of materials. Undercooking of materials increases the risk of fat and water separation during pasteurization. To ensure that the materials are not too hot when they are added to the cutting bowl, prior to the addition of liver, cold water can be applied to the bowl within the double-jacket space, which cools the bowl itself. This leads to a decrease in temperature of the cooked and hot meat and fat material to around 60 °C before liver is added. On a large-scale production, the addition of well-chilled liver to fully cooked and hot meat and fat materials takes place, knowing that a small degree of liver tissue will become denatured as a result. For example, if 25% functional liver is required within the recipe, then around 28% liver is introduced into the hot mass of precooked meat and fat knowing that around 3% liver will be denatured as a result of working with a mass above 60 °C at the point that liver is introduced. This saves the time required for the hot mass to cool to around 60 °C. Care has to be taken that the addition of liver does not cause the overall temperature of the sausage mass to drop below 35 °C as the risk of fat separation would be greatly enhanced. Therefore, frozen or semifrozen liver should not be used or only if the amount of liver introduced is quite small. Another way of reducing the temperature of the hot meat and fat mass to around 60 °C quickly is the addition of small amounts of ice. Once a temperature of around 60 °C is obtained liver can be introduced without becoming denatured.

Another method of working with a cooking bowl cutter is that only fat materials such as pure fat (back fat) or jowls are processed in the bowl cutter with added salt and nitrite and, once a temperature of around 75 °C is reached, precooked and reheated materials such as PHM can be introduced into the hot fat materials. The addition of reheated, or warmed, PHM reduces the overall temperature to around 60 °C and all is cut until finely comminuted meat and fat particles are obtained. As the temperature has already dropped to around 60 °C owing to the introduction of warmed-up PHM, liver can be added without being denatured. Reheating of cooked PHM is usually accomplished by placing it in hot water for a while until it is warm. Pork skin is most commonly precooked separately before being added to the sausage mass but can be thermally treated directly in the cooking bowl cutter together with all other meat and fat materials. The major advantages of working with a cooking bowl cutter are the significantly reduced amount of handling of the materials to be processed, the exact control of temperature during cooking and the fact that there is no cooking loss at all during precooking of the materials. Development of curing colour also occurs in the bowl cutter and no precuring is required.

Another (not so common) method of precooking meat and fat materials is to utilize a cooking mincer in which the cured meat and fat material pass through a long cylindrical metal tube. Both the mincer spiral itself as well as the metal tube containing the spiral are hot and the material is minced with the 3–4 mm blade and is cooked whilst it passes through the mincer.

Whichever process is used to cook or precook the meat, the temperature of the finely cut meat and fat materials should be around 60 °C once the liver is introduced. Upon addition of the liver, all the ingredients are cut again at a high knife speed and the temperature of the finished sausage mass should be above 35 °C.

### **25.3.2 Production of finely cut liver sausage with precooked chilled materials**

Producing liver sausage using precured, cooked and chilled materials is rarely practised. Within this method, all meat and fat materials are precured through the application of salt and nitrite and subsequently fully cooked in steam or in a hot-water bath. Temperatures of 85–90 °C are applied so that 70–72 °C is reached in the core of the cooked materials. They are then placed in the chiller. Cured and precooked PHM is occasionally used as well. The cooked and chilled materials are placed in the bowl cutter and all is cut at a high knife speed until a fine paste is obtained. The volume of materials that is lost during precooking is added back as broth during the cutting process. Liver is generally precut and salt and nitrite are added at the end of the cutting process once bubbling is seen. Such precut liver is added to the finely cut meat and fat materials and all is well emulsified at a high knife speed. Spices and additives are added to the sausage mass generally towards the end of the entire process. Colour enhancers, based on ascorbic acid or GDL, must not be added together with nitrite. The disadvantage of this method is that even more handling is required as hot precooked materials are cooled in the first place, which uses a high level of energy, labour and space. Also, cutting solid and chilled fat as opposed to hot and liquid fat never results in the same high degree of comminution and the final product frequently displays a degree of sandiness, thus creating a rough mouth feel. The emulsification capacity of liver protein is at a higher level when material is processed in a hot state which reduces the risk of fat separation during final cooking of the product.

### **25.3.3 Production of coarse liver sausage**

There are a number of ways to produce coarse liver sausages. The type of fat used in a coarse liver sausage is more crucial than in a finely cut product because a coarse product is mixed only, whilst in a finely cut product a fine and creamy mass is obtained so that the fat is emulsified very effectively. In coarse liver sausage, fat materials with enhanced levels of connective tissue

such as jowls and fatty pork belly are predominantly processed as such material is more stable against the impact of heat during subsequent pasteurization of the product.

A very common and simple way of producing coarse liver sausage is to mince precured and cooked warm meat and fat materials together with chilled raw liver with a blade of around 3–8 mm. Spices, colour enhancer, salt and nitrite are added to the minced materials, and all ingredients are mixed well. Such minced and mixed products exhibit the greatest tendency for separation of fat during thermal treatment as the surface area of the liver is quite small because it has only been minced. Spreadability of the finished product is sometimes not perfect either as such a sausage mass consists of coarse particles only. Very coarsely minced materials often result in crumbly products. Mincing of materials, especially liver, with a smaller blade increases the surface area and spreadability will be improved. Increased levels of fat as well as added broth also aid spreadability. However, coarse and almost non-spreadable liver sausages are sometimes desired as they have a traditional feel to them. The occasional separation of fat during pasteurization is not of concern in such home-made style products. To increase the surface area of liver and thus to reduce the risk of fat separation, the liver can be cut in the bowl cutter until bubbling is observed, using the same method as described for the finely cut liver sausage. All other precooked meat and fat materials are minced with a suitable blade and the finely cut liver is mixed with the minced materials. Mixing of the total mass takes place in a gentle way while spices, herbs, salt and nitrite are added until the desired level of flavour and saltiness is reached.

Yet another, and very common, method of producing coarse liver sausages is to mince all the precooked meat and fat materials as well as the chilled raw liver with the desired blade first. Then, around 20–40% of the uncooked fine liver sausage mass (see Section 25.3 and, in particular, Section 25.3.1) is added to the coarse materials. This method increases spreadability significantly and reduces the risk of fat separation. A smooth and highly spreadable finished product is obtained this way.

#### **25.3.4 Filling and cooking**

The period of time between obtaining a finely emulsified or coarse liver sausage mass, filling and subsequent pasteurization should be kept as short as possible. Most commonly, staff involved in producing the emulsion, filling the product and subsequent pasteurization ensure that no unnecessary delay takes place within those important processing steps. This is especially important in liver sausages produced using the hot method where the finished sausage mass exhibits a temperature around or above 35 °C. Prolonged periods of delay between obtaining the emulsion or coarse sausage mass and the thermal treatment following filling causes the sausage mass to cool considerably. A decrease in temperature causes the fat molecules to clump together to form

larger particles which cannot be kept properly emulsified and covered with liver protein during subsequent pasteurization. This increases the risk of fat separation during pasteurization. In addition, the sausage mass has an elevated temperature, a high  $A_w$  and high levels of sugar (glycogen) and provides a perfect breeding ground for bacteria. In the worst-case scenario, extremely long resting times, besides increasing the risk of fat separation, can lead to souring within the sausage mass even before the product is thermally treated. The addition of spices such as fresh onions increases the risk of souring as onions are high in pyruvic acid. Liver sausage mass, fine or coarse, is commonly filled into waterproof casings through the application of a vacuum so that no loss in weight can be observed during pasteurization. Removing any air entrapped within the sausage mass avoids discolouration within the air bubbles inside the finished product. In a tightly filled and air-free product the compact sausage mass expands during pasteurization and the casing used presents a counter-force against expansion of the sausage mass. The risk of fat separation during pasteurization is enhanced by the presence of air bubbles as the counter-force is missing within air bubbles, which means that the matrix of liver protein covering fat globules can break. Coarse liver sausage is also occasionally filled into natural casings such as beef fat end. If a finely cut liver sausage mass becomes too cold, it can be placed again into the cooking bowl cutter (if available) and the mass can be reheated to 35–40 °C before filling. However, this method addresses only the risk of fat separation. It does not resolve the fact that souring or excessive bacterial growth could have taken place within the long period of delay and such situations should be avoided. Also, reheating is another processing step and thus very costly.

Following filling, the product is pasteurized to 78–80 °C by applying steam or placing the product in a hot-water bath until a temperature of 72–74 °C is obtained in the core (72 °C being the usual temperature obtained). If pasteurization is based on the  $F$  value (which is not often so in practice), an  $F_{10/70}$  of above 30 min (see Chapter 40, Section 40.2) should be obtained for shelf life purposes. Liver protein starts to coagulate at temperatures above 60 °C and no cooking loss is seen as a result of filling the product into waterproof casings even at a core temperature of 72–74 °C. These temperatures also ensure that all myoglobin and, more importantly, haemoglobin have been fully denatured and all enzymes possibly present in the meat and fat materials as well as the spices are deactivated. Core temperatures of 74 °C ensure that *Lactobacillus* spp., which could cause souring, formation of gas and discolouration, are destroyed.

Products filled into natural casings are commonly pasteurized in a hot-water bath and, by cooking several batches in a row, a small degree of fat separation (melting of fat) during pasteurization of the products over time creates a flavoursome cooking broth positively contributing to the flavour overall of the product. During pasteurization the matrix of liver protein covering fat and water does not change because a strong protein–protein

interaction takes place. The globular liver protein matrix holds particles of fat together or forms a three-dimensional matrix covering the entire surface of fat particles during thermal treatment. The liver protein matrix itself is very brittle and cannot withstand pressure. Combined with sufficient levels of fat, this contributes to the spreadability of the finished product. Elevated levels of collagen, which turn into gelatin during cooking, also contribute to a smooth mouth feel and spreadability.

The thermally treated product is usually showered for a short while before being placed into the chiller. As with other heat-treated meat products, reducing the temperature from 55 to 10 °C should be accomplished fairly quickly as surviving spores can germinate at temperatures above 10 °C. The internal temperature should furthermore be reduced below 4 °C quickly to avoid growth of surviving pathogens such as *Salmonella* spp. High-quality liver sausages, fine or coarse, once cooled down are frequently dipped in hot wax which is around 90 °C. A certain type of waterproof casing can be used for this purpose which supports excellent adherence of wax to the surface of the casing. Occasionally, products filled into natural casings of diameter around 40–50 mm are dipped into hot wax as well. Dipping of the product into wax has the advantage that the final product has a visually very attractive traditional appearance. The amount of wax connected to the surface of the product accounts for 2–5% of the total weight. Wax costs less than the price at which the finished product is sold for, thus being an economical benefit. In addition, the layer of wax represents an additional layer of protection against oxygen and light, thus supporting the stability of colour and flavour within the product. Finally, dipping of products into the hot mass of wax inflicts some degree of post-cook pasteurization on the surface, thus reducing the microcount on the surface of the product especially if natural casings have been used. Finely cut liver sausage mass which is to be retorted and therefore shelf stable is frequently filled into retortable waterproof casings. Great care has to be taken that the difference between pressure within the thermally treated product and the counter-pressure applied during retorting is as little as possible to avoid bursting of the casing. The counter-pressure to be applied during the retorting and cooling phases should be such that the pressure within the product does not exceed the counter-pressure applied by more than 0.2–0.3 bar to avoid bursting of the casing. Such retorted products are generally thermally treated at around 105–110 °C only, but for a prolonged period of time. They are not heated to 115–120 °C as the risk of fat separation is greatly enhanced at such elevated temperatures. Products are also frequently filled into cans, and flat cans with little height are preferred as heat penetrates much more quickly through a flat can, thus allowing a gentler method of retorting, which reduces the risk of fat and water separation.

Shelf-stable but pasteurized products filled into waterproof casings are occasionally produced. This is based on the principle that a product with a high fat content of around 40%, 2% salt, around 1% sugar and 1–1.5% dry milk powder shows an  $A_w$  of or below 0.95 (assuming that little or no broth

is added). Thermal treatment of the product to a core temperature of 74 °C will destroy all vegetative bacteria and any surviving spore formers require an  $A_w$  above 0.95 to germinate.

### **25.3.5 Smoking**

Quite often, coarse liver sausages are filled in permeable casings, but most commonly natural casings from beef (fat end) or other larger-diameter materials are used. Applying a touch of smoke at temperatures around 20–30 °C during the cooling period of the thermally treated product is practised as it contributes nicely to the flavour and a degree of surface preservation occurs as well owing to the application of phenols, formaldehyde and other organic acids present within smoke. The process of smoking should take place during the cooling period as it is energetically beneficial. In the case when the thermally treated product is completely cooled to, for example, 2 °C and then smoked, condensation will occur as soon as the cold product is removed from the chiller and exposed to temperatures between 20 and 30 °C during smoking. To avoid this the product would need to be dried first at around 50 °C to remove condensation water before the product can be smoked as an uneven smoke colour can be obtained by applying smoke on to a wet surface. Formation of condensation water as well as the additional step of drying can be avoided if the product is smoked whilst it is cooling once the temperature of the product is around 20–30 °C. Upon completion of smoking, which generally lasts between 20 and 45 min, the product is further cooled until the final storage temperature of 0–2 °C is reached.

### **25.3.6 Storage**

Finely cut or coarse liver sausages packed in waterproof casings are stored at temperatures between 0 and 4 °C. However, since liver sausages are highly perishable, a storage temperature of maximum 2 °C is preferred to 4 °C. Products filled into natural or other permeable (non-waterproof) casings are also commonly modified atmosphere packed and a gas mix of around 20–30% carbon dioxide and 70–80% nitrogen is applied. Modified-atmosphere packed products are stored under chilled conditions. Care has to be taken during the packing of permeable casing products that condensation water does not occur despite the packed product being stored under chilled conditions.

Discolouration of the product, formation of slime and off-flavours can be observed quickly if a product in permeable casings is stored at around 4 °C because some spoilage bacteria are still active at these temperatures especially if free water was obtained on the surface of the product as a result of condensation during packing. Retorted small-diameter and portioned products are commonly modified atmosphere packed and four to ten pieces are often contained within one packaging unit which can be stored at room temperature.

## 25.4 Production of liver pâté

Pâté is a French word literally meaning 'covered in pastry'. Liver pâté can be produced in an endless variety of ways. As such diversity exists, it is virtually impossible to specify one single method best describing the manufacturing process. Pâté as such is an upmarket French meat (charcuterie) product and liver pâté is basically an extension in the product range based on liver sausages. Terms such as rillettes, terrine and galantine are frequently used instead of pâté. Game meat such as venison or rabbit are frequently used. Liver pâté is often produced in the same way as fine or coarse liver sausage, the difference being in the packing of the product, the type of heat treatment applied and the packaging of the finished product. An occasional difference in the treatment of the precooked meat material is that the material is only semicooked to a temperature of around 60 °C so that the semicooked muscular protein is not completely denatured. The inclusion of salt during the cutting process afterwards solubilizes non-denatured protein to a certain degree. During subsequent thermal treatment of the pâté mass, activated protein from the partially precooked material contributes to a firmer texture in the finished product than in a liver sausage. This is frequently desired in a pâté and even makes it sliceable.

One way of producing pâté is to fill moulds made from ceramic, aluminium or some kind of heat-stable plastic with finely cut or coarse liver sausage mass with a core temperature of above 35 °C. The moulds are not filled right to the edge, leaving around 1–2 cm space on top. As with the liver sausage, long periods of time between making the actual sausage mass, filling and thermal treatment should be avoided to reduce the risk of fat separation as well as of souring. Filled moulds are subsequently thermally treated with dry heat (baked) at temperatures between 85 and 95 °C until 72–74 °C is reached in the core. Once the product is cooled, a layer of gelatin solution as well as decorative items such as a slice of orange is applied to the pâté. Those decorative items are placed on the chilled pâté together with a thin layer of gelatin which solidifies shortly after fixing the decoration on the pâté. Once the layer of gelatin is solid, additional warm gelatin is added until the mould is almost filled to the edge. Chilled pâté can also be flamed to create a burned and quite dark appearance on the surface before warm gelatin solution is applied. The addition of gelatin seals the product within the mould and all possible gaps between the mould and pâté are filled with gelatin, which avoids discolouration as oxygen cannot affect the product in those gaps any longer. All is completely cooled before being packed into vacuum-shrink bags and a proper vacuum is applied. A short dip into hot water completes the packing process and a visually very attractive product is obtained, which is regularly sold in shops by cutting a slice of pâté from the mould in front of the customer. Some pâté is also sliced by the manufacturer into slices exhibiting a thickness between 1 and 2 cm before being vacuum packed. An easy way to remove the chilled pâté from the mould is to grease the mould

with a thin layer of fat or oil before it is filled. Once the product has been filled, cooked and cooled, the mould is dipped for a short period into hot water thus melting the surface of the pâté which is in contact with the mould, allowing easy removal if the mould is turned upside down.

Liver pâté provides the perfect opportunity to be creative as basically all different types of additive such as red wine, brandy, cognac, rum, herbs, peppercorn, pistachio, olives and countless other materials can be mixed into the pâté mass before being filled into the mould. Liver pâté may also be filled into moulds which have been lined with pastry. Before placing pastry into the mould, a thin non-stick plastic liner is occasionally inserted into the mould which prevents the dough from sticking to the mould during heat treatment. The warm sausage or pâté mass is placed into the pastry-lined mould and a pastry lid is attached, completely covering the pâté mass. The lid has an opening such as a small square cut out of the dough as hot air has to be able to escape during thermal treatment of the product. Again, the pastry-lined mould is not filled right to its border and around 1–2 cm of space is left between the liver pâté and the pastry lid before being baked (dry heat) in an oven set to 120–160 °C until the product reaches 74 °C in its core. The temperature in the oven depends also on the type of pastry, or dough, being used. The dough must be completely baked during the process with the liver pâté reaching 72–74 °C only. After heat treatment, the product is placed in the chiller and subsequently removed from the mould. A hot solution of gelatin is prepared and, once again, all different types of wine or other alcoholic spirits are introduced into the hot gelatin solution which is added to the pâté through the hole in the lid until all the spaces between the pâté mass and the lid are completely filled. The space between the pâté mass and the pastry lid increases during baking because of the rising action of the dough as well as the subsequent shrinking of the pâté mass during cooling of the thermally treated product. Once all the solution of gelatin is added, the product is afterwards cooled to 0–4 °C before usually being vacuum packed and sold as whole to delicatessen shops.

Sliceable liver pâté is also produced in certain parts of the world; this is more like a cooked sausage filled into a pastry-lined mould, baked as described above and a gelatin solution is used to fill the gap between sausage mass and the lid made from pastry. The sausage mass is produced from uncooked non-cured meat and fat as well as ice or water as described in Chapter 12, with the only difference being that around 10–15% raw liver is introduced into the mass during the initial stage of the cutting process. Additives such as phosphates, salt, nitrite, colour enhancer and spices are introduced and all materials are cut at a high speed at around 14 °C. The finely cut mass can then be used to fill the pastry-lined moulds, or occasionally natural casings such as beef fat end or hog casings. Commonly, spices such as cracked pepper or herbs are mixed into the fine mass. In order to create coarse sliceable pâté, precured meat trimmings are minced with a 3–8 mm blade and mixed into a fine emulsion by adding between 30–70% minced materials into the finely cut mass. Once

again, materials such as mushrooms, pieces of orange and others are mixed into the mass before being filled into the pastry-lined mould. The moulded products are then treated as described above by attaching a pastry lid and baking to a core temperature of 72–74 °C before being cooled and subsequently filled with warm gelatin solution or by cooking with steam at 78–80 °C until 72–74 °C is reached in products filled into natural casings.

Another very simple method of producing pâté is to mince raw untreated fatty meat trimmings with the desired blade and mix in salt, spices, milk and eggs. The mass is mixed until a tacky consistency is obtained and either filled into prefatted moulds without any liner or, as described above, into pastry-lined moulds. Once again, any possible condiment such as alcoholic spirit, spice or fruits can be introduced. Quite often, such pâté is produced without nitrite, giving the product a traditional feel, and liver is often not part of the product either.

## **25.5 Summary of critical production issues for liver sausage**

- 1 Materials to be used must have a pH below 6.2 and a low bacteria count ( $10^2$ – $10^4$  per gram of product).
- 2 Precured meat and fat material should be cooked with steam or in a hot-water bath until a temperature of 70 °C is reached.
- 3 Alternatively, the non-cured materials should be cooked in a cooking bowl cutter until a temperature of 70 °C is reached. Salt and nitrite should be added at the beginning of the cutting–cooking process.
- 4 The bacterial count of the liver must be low and no preblanching should take place.
- 5 Cured and cooked meat and fat materials should be cut at a high knife speed until a fine paste is obtained; broth can be added to replace the amount lost during precooking of meat and fat materials if the precooking is carried out with steam or in a hot-water bath.
- 6 The finely cut and hot mass should be cooled to below 60 °C prior to the addition of liver.
- 7 Precutting of the liver prior to its addition to the finely cut meat and fat materials is not essential (liver protein is water soluble) but is of advantage.
- 8 The total mass is emulsified whilst cutting at a high knife speed.
- 9 The temperature of the finished emulsion should be above 35 °C.
- 10 Filling and pasteurizing of the sausage mass must occur immediately afterwards without delays.
- 11 Thermal treatment should take place at around 78–80 °C until 72–74 °C or an  $F_{10/70}$  greater than 30 is reached in the core.
- 12 Smoking of the products at 20–30 °C, if applied, should take place during the cooling period to avoid formation of condensation water.

- 13 Cooling of the product should ensure that a temperature below 5 °C is reached within 10–12 h.
- 14 The formation of condensation water should be avoided during packing of products, which are filled into permeable casings.
- 15 The finished product should be stored between 0 and +2 °C.

## 26

# Typical spreadable liver sausage and liver pâté products from around the world

### 26.1 Fine veal liver sausage (Austria)

Veal liver sausage is seen as a delicacy in Austria as veal liver itself is quite expensive. Veal liver sausage is a finely cut product containing around 30% liver with veal liver accounting for around 50% of the total amount of liver (around 15% of total mass). The rest of the meat and fat material used is veal meat (very young beef) and commonly boneless veal breast. Besides that, some fatty pork, or pork fat, provides the product with some fat material. Overall, a veal liver sausage contains around 30–35% fat, 10–15% veal liver, 10–15% pork liver and around 40–45% meat, with veal meat accounting for around 30–40% of the meat material. Pork skin or PHM is generally not used in this high-quality product.

The finely cut sausage mass is produced either in a cooking bowl cutter or in the conventional way by processing precured and precooked materials, which have been treated with steam or have been placed in a hot-water bath. Liver is generally precut (even though this is not technologically required) and 1–2% sweet cream is frequently added into the sausage mass as well. A touch of vanilla rounds off the flavour. Salt is present in the final product at around 1.8% and spices utilized are white pepper, cardamom, mace and ginger. Nitrite and colour enhancer (ascorbic acid or ascorbate) are added as well. The finely emulsified product is filled into waterproof casings and pasteurized at 78–80 °C to a core temperature of 72 °C. Once cooled, the chilled product is frequently dipped in wax and the finished product should be of a light-pink colour. It should have a very creamy smooth texture and a pleasant taste of liver rounded off with vanilla.

## **26.2 Fine liver sausage (Austria and Germany)**

Finely cut liver sausage is commonly produced from 30–35% fat, 25% liver and 5–10% pork skin. Lean meat makes up the final percentage of the ingredients. Pork liver is the preferred choice and all the meat and fat materials should be pork based as well. Commonly, cooked PHM is processed with hot pork fat and/or jowls. A fine emulsion is obtained either by using a cooking bowl cutter or in the conventional way by cooking precured meat and fat materials in a hot-water bath. The product is usually filled into waterproof casings and thermally treated with steam or in a hot water bath at 78–80 °C to achieve a temperature of 72 °C in the core.

## **26.3 Coarse liver sausage (Austria and Germany)**

Germany is especially known for its endless variety of liver sausages and it is an almost impossible task to give one standard recipe from Germany.

Coarse liver sausage is usually made from 20–30% fine liver sausage mass and 70–80% minced materials such as raw pork liver (around 15–20%) as well as precured and precooked fatty pieces of pork. Reheated PHM as well as fatty pork belly or jowls are frequently used as well. The precooked and hot materials, as well as the liver, are minced with the 3–6 mm blade and added to the fine emulsion. All the ingredients are mixed gently while spices, salt, nitrite and colour enhancer are added. Salt and nitrite are generally just required to flavour the raw liver, as all the other cooked materials have already had salt and nitrite added during precuring. The level of salt in the finished product is around 1.6–1.8%. Spices such as mixed herbs or fried onions are commonly added to coarse liver sausage and the well-mixed mass is filled into waterproof casings. Occasionally, natural casings are used instead. Whichever casings are used, the filled product is thermally treated at around 78–80 °C until a temperature of 72 °C is obtained in the core. Some products filled into natural casings are smoked whilst others are dipped into hot wax to add value to the product.

## **26.4 Fine liver sausage (Russia and South Africa)**

Fine liver sausages in Russia and South Africa are commonly produced from around 35% precooked pork fat, 8–10% precooked pork skin and 20% hot broth. 25–30% liver is processed as well. Hot fat and skin are cut at a high speed while adding broth. Milk protein (caseinate) or soy isolate is added at an amount of 2–3% of the total sausage mass (including liver). After cutting for a while until a shiny mass has been obtained, the (precut) liver is introduced as well as around 1–2% milk powder. Starch is also commonly added at 4–5% and all the ingredients are cut for a while at a high

knife speed. Spices, salt (1.2–1.4%) and nitrite are introduced and the finished mass is filled into waterproof casings and pasteurized at 78–80 °C until 72 °C is reached in the core.

### **26.5 Coarse brandy liver pâté in a pastry cover**

Coarse brandy liver pâté consists of 20–40% fine liver sausage mass as well as 60–80% precured and precooked minced materials such as fatty pork trimmings, jowls as well as raw pork liver. Cooked pork skin or PHM is only occasionally used in such high-quality pâté. The hot and precooked meat and fat materials as well as raw liver (around 20%) are minced with the 6–8 mm blade and are mixed well with the warm fine emulsion. The level of salt in the finished product is 1.8%. Nitrite and colour enhancer are most commonly applied to obtain a cured product but in rare cases the pâté is produced without nitrite to obtain a more traditional product. During mixing, ingredients such as mixed herbs are introduced as well as brandy. Brandy is added into the pâté mass at a sufficient level that its presence can be detected, but it does not overpower all the other flavours. The warm mass, at a temperature of above 35 °C is filled into pastry-lined moulds and baked at around 120–150 °C until 74 °C is reached in the core. Upon cooling to around 4 °C, a gelatin solution containing brandy is added to the product through the hole in the pastry lid before it is placed in the chiller again.

### **26.6 Fine pepper–chicken liver pâté in a mould**

The finely cut pâté mass is obtained by cooking precured fatty chicken trimmings and chicken skin. A typical recipe would contain 30% chicken liver, 20–30% chicken skin and 40% chicken thigh meat. Nitrite and 1.8% of salt are present in the finished product. The meat and skin materials are either precooked with steam or hot water or cooked in a cooking bowl cutter up to a temperature of 68–70 °C before being cooled below 60 °C. Raw liver is introduced and all the ingredients are well emulsified at a high knife speed. Cracked pepper is introduced into the finely cut emulsion and all ingredients are mixed gently before being filled into prefatted molds. Baking takes place at around 85–95 °C until 74 °C is reached in the core. After being chilled to a temperature of 4 °C the surface of the product is flamed with a burner to obtain a rusty-burnt appearance on the surface of the product. Hot gelatin is added to fill up all gaps between the pâté mass and mould as well as to cover the pâté. After being cooled again to solidify the gelatin solution, the product is sold shrink packed and the mould is commonly sold with the product.

### **26.7 Pâté de campagne (France)**

Cured and cooked PHM and non-cured uncooked fatty pork belly are minced together with raw liver using a 4–6 mm blade. A typical recipe contains 30% liver, 30% cooked PHM and 40% fatty pork belly. Occasionally, 10–20% fine-liver-sausage mass is added to increase the smoothness of the product. All ingredients are mixed well, and nitrite and salt are added to cover the amount of pork belly and liver as those materials have not been precured. The level of salt in the finished product is around 1.8%. Spices such as pepper, nutmeg, thyme and marjoram as well as eggs and flour (around 2–3%) are gently mixed into the sausage mass. Fried onions at 1–2% are added and the well-mixed mass is filled into prefatted moulds and baked at 120–140 °C until a temperature of 72 °C is obtained in the core. Hot gelatin solution is added to the chilled product to fill up the mould before being placed in the chiller again. Once the layer of gelatin is solid, the product including the mould is vacuum shrink wrapped.

### **26.8 Pâté de viande (France)**

A finely cut base emulsion consisting of raw untreated meat and fat materials as well as water and/or ice is obtained as described in Chapter 12 by either following the lean-meat method or the all-in method. The base emulsion contains around 45% lean meat, 25% fat and 30% water and ice. Additives such as phosphates, salt (1.8%), nitrite and colour enhancer are added and the ingredients are cut at a temperature of 12–14 °C. Precured materials such as lean pork belly as well as lean pork shoulder meat are minced with the 10 mm blade and mixed into the base emulsion at a ratio of 50:50, with the meat material being made up of 25% lean pork belly and 25% lean shoulder meat. Spices applied are pepper, mace, garlic and cloves. The well-mixed mass is filled into natural casings of 50–70 mm diameter and cooked with steam or in hot water at 76–78 °C until a temperature of 70 °C is reached in the core. The chilled product is consumed cold.

### **26.9 Rillete porc et oie (France)**

Rillete porc et oie is commonly made from 25–30% boneless fatty goose meat, 50% pork shoulder meat, 10% pork flare fat and 10% goose fat. The goose fat and pork fat are placed in pots and heated until liquid and hot. Fist-sized pieces of shoulder meat are added and all the ingredients are cooked for around 30 min to 1 h. Pieces of goose meat are cut in small pieces and added into the pot as well and cooked for around 30 min. The entire mass is constantly stirred during the process to avoid burning of the materials.

Spices such as white pepper, pimento, cinnamon and clove are added as well as water and salt (which can be nitrite salt or common salt, at 1.2–1.6%) and all the ingredients are cooked for 4–5 hours. After thorough cooking, the meat is removed and shredded (or minced) to obtain a fibre-structured material. Fat is largely removed from the liquid and the fibre-structured meat is mixed with the liquid. Cognac is added (around 3–5% of the total mass) and the mixture is filled into the moulds. Filled moulds are placed into the chiller to cool quickly to avoid bacterial growth.

### **26.10 Pâté de Bretons (France)**

Pâté de Bretons is produced from a finely cut paste, visible meat and fat materials, and liver. Within a total batch of 100 kg, around 10–15 l of hot milk (around 50–60 °C), 5–7 kg of pork liver, 5–7 kg of cooked pork skin, 3–5 kg of onions and 3–5 kg of hot pork fat are cut until a fine paste is obtained. In addition, around 20 kg of pork liver as well as 40 kg of uncooked rindless pork jowls are minced with the 8–10 mm blade and mixed with the fine mass. Salt (including nitrite) is added at around 1.6–1.8%, and phosphates at around 0.2%; colour enhancer such as ascorbic acid and spices such as pepper, cinnamon, clove, cardamom and ginger are introduced as well as alcoholic materials such as cognac or brandy and all the ingredients are mixed well. The well-mixed mass is filled into moulds and baked (85–90 °C) or steam cooked (78–80 °C) until a temperature of 74 °C is reached in the core.

## 27

# Burgers, patties and crumbed products

Controversy arises when the origin of burgers and meat patties is discussed. While some say that people in eastern Europe eating tartare (a food product containing finely minced very lean beef mixed with raw egg and eaten raw on bread) were the inventors of the burger, almost everybody agrees that the first hamburger was invented in the USA.

In the USA, terms such as 'ground beef' or 'chopped beef' are synonymous. However, the term 'ground beef' refers in most other countries to minced meat only and has nothing in common with a hamburger or any formed product made from minced meat. Generally, ground beef in the USA is produced from fresh and/or frozen beef with or without seasoning. The fat content must not exceed 30%. Ground beef must also not contain added water, and no fillers such as starch or flour are allowed. Frequently, beef cheek meat is incorporated into ground beef at levels of up to 25%. When a certain cut of meat such as topside is utilized for the production of ground beef, the product can be labelled 'ground beef topside' and all meat utilized must then originate from topside. Because certain cuts of beef are very lean, beef fat is often introduced and the final product is then called 'ground beef, beef fat added'. The standard size of a burger in the USA is 112 g, which is 4 oz or a  $\frac{1}{4}$  lb.

Burgers and patties are produced in endless different ways with regard to types of meat utilized, form, shape, nutritional value and cost considerations, as well as religious reasons; it is virtually impossible to cover all those aspects of producing burgers or patties fully within this chapter. In the USA as well as in several other countries, the term 'hamburger' is generally associated only with burgers made with processed beef. However, products called hamburgers produced from turkey and other types of meat are produced in

other parts of the world. Whilst some burgers consist of minced beef, with some salt and spices, others are a mix of minced meat and salt without any spices whatsoever. Some 'pure-beef' burgers are made from beef meat only without any salt, spices or added water, resulting in a crumbly texture preferred by some consumers. Other types of burger commonly contain, besides meat and fat, small amounts of added water as well as additives such as salt, phosphates, spices and flavour enhancers.

As an extension of a burger, a patty is generally 'the poor man's burger' and contains, besides the usual ingredients of a burger, elevated levels of water as well as additives such as protein, bread crumbs and/or starch. The quality of a burger, or patty alike, is to a great extent determined by the willingness of the consumer to pay for 'quality'. The quality or sensory properties of a burger or patty depends on parameters such as the breed of animal from which the meat originates, the cut of the carcass utilized, the age of the animal, the pH value of meat to be processed, the diameter of the blades used during mincing, the forming systems in place and, especially, the level of non-meat ingredients within the burger or patty mass itself. Burgers and patties are now mostly stored frozen and are cooked (usually by grilling or frying) from frozen.

## 27.1 Selection of raw materials

Burgers or patties can be divided into countless different quality levels based on the amount of meat and fat present within the finished product, the amount of water added to the mass and the level of non-meat ingredients used. Religious reasons also determine the type of meat used. Regardless of the recipe itself it is important that, once a recipe is established, it is followed precisely with regard to meat and fat content as well as the carcass cut, or trimmings, used. Other parameters such as the temperature of the meat mass and level of non-meat ingredients must be followed precisely as well in order to achieve consistent forming conditions, frying properties and weight loss during heat treatment. Parameters such as the texture and taste of the product are only consistent when a consistent meat mass is obtained following a consistent manufacturing process at all times.

No bones or particles of bones or any other foreign bodies such as pieces of glass or metal must be present within the meat and fat materials processed. The fat present must not display any signs of rancidity and the bacteria count of meat and fat materials should be around  $10^2$ – $10^4$  per gram of product, with  $10^3$  per gram of product often seen as the maximum. The meat and fat materials processed are frequently boneless cow meat, beef plates or beef flanks as well as other beef trimmings. The choice is often determined by availability as well as the cost of the material itself, with the prerequisite that the fat content in the finished product remains constant. Producers of 'quality' burgers and patties use more fresh than frozen meat, because the use of

frozen meat results generally in higher cooking losses due to the damage done to protein by the formation of ice crystals during the freezing process (see Chapter 4, 4.7 Section). However, large-scale producers predominately process frozen and semifrozen materials as chilled materials can only be stored for a very limited period of time before the number of bacteria exceeds specifications. It is not possible to select whether or not DFD meat (see Chapter 4, Section 4.1) is used when blocks of frozen meat or chilled meat purchased from various supplies are processed. As a result, the WHC and solubility of protein in the meat are outside the manufacturer's control. However, using DFD meat in burgers and patties is not a significant disadvantage with regard to shelf life, because a large quantity of burgers produced are stored frozen. Furthermore, the high pH values of DFD meat are also not of concern, as burgers or patties are most commonly produced without the addition of nitrite and formation of curing colour is not wanted. It is very unlikely that all, or a large amount of, the meat processed in one and the same batch will be of DFD character as meat and fat materials originating from several different animals are most often processed within the same batch. This therefore reduces the impact of any DFD meat present within the total batch.

Occasionally, very lean beef such as topside is processed and some beef fat is added to obtain the desired level of fat. To simplify the process, one type of CL-grade beef, which will provide the desired fat content in the finished product, is often processed on its own. If this is not possible, a lean blend as well as a fat blend are produced first and are then mixed at the proper ratio to obtain the set level of fat. Expressed in another way, a certain amount of a certain CL grade (such as 85% CL grade) material is mixed with another fixed amount of another CL grade material (such as 50% CL grade), resulting in the desired level of fat within the product. Online fat analysis during mixing ensures a constant level of fat in burgers produced on a large scale. In burgers and patties made from pork, fatty trimmings are generally processed to reach the desired level of fat within the meat mass. Chicken skin is often used in chicken burgers and levels of between 5% and 15% are introduced. In chicken or turkey patties, the use of chicken-skin emulsion made in a ratio of 1:4:4 (see Chapter 12, Section 12.2) is also common. Fat emulsions produced with oil, soy protein and water in a ratio of 1:5:4 (1 part of soy isolate, 5 parts of water and 4 parts of oil) can replace fat within a low-fat burger and provide a smooth texture and mouth feel in the finished product. Burgers and patties made from turkey are also on the market and quite a few of these chicken and turkey products are sold as low-fat or low-sodium products.

## 27.2 Selection of additives

Salt is the most commonly applied additive in meat products and the level of salt in burgers or patties varies between 0.2% and 1.5%, or between 2 and 15

g, per kilogram of mass. Generally, the level of salt is kept low, at around 0.7–0.9%, but customers in some countries prefer a high level of salt at around 1.5% or 15 g per kilogram of product. Salt acts pro-oxidatively and speeds up rancidity over time. Levels up to 0.9%, however, have little impact on speeding up rancidity but support the activation of protein during mixing of the product prior to forming as well as contributing to flavour.

Water is frequently added to burgers and especially to patties because water is the least expensive raw material. Water is also required for enhanced juiciness of the product and to act as a solvent when phosphates and salt are introduced into the mass to solubilize muscular protein. When these additives are applied, added water is firmly bound and a succulent product is obtained at reduced cost in terms of raw materials. The level of water added to burgers or patties varies between 0% and 25% and care has to be taken that water added does not contain nitrate or nitrite as only 2–5 ppm of nitrite per kilogram of product can produce a pinkish colour in non-cured products.

Phosphates (see Chapter 5, Section 5.1.2) are commonly introduced at levels between 1 and 3 g per kilogram of product into the meat mass when water is added and especially if the level of added water is higher than 5%. Phosphates delay rancidity within the product during prolonged periods of storage, because phosphates chelate heavy metal ions such as iron and copper, which act pro-oxidatively. Phosphates are generally not added to burgers which do not have any added water or to burgers in which water is only added up to 5% of the total mass. This is because the introduction of salt solubilizes protein to a small degree during mixing or mincing, thus supporting immobilization of water. In a large number of countries burgers should not display a significant degree of water binding as a somewhat loose-textured product is desired. As a result little or no phosphate needs to be added.

The addition of spices is optional and pure-beef burgers commonly do not include spices as the original beef flavour is all that is desired. However, to increase the product range, spices such as black pepper, chilli and others are now frequently used. The addition of spices to patties is very common as large amounts of water as well as non-meat materials are often present within a patty mass. Onions are high in pyruvic acid, which can cause discolouration in burgers and the utilization of dried onions or less pungent onions is advised. As a word of warning, natural spices can contain nitrate or nitrite at a level that may produce pink-coloured products.

In patties containing very little meat, colours such as carmine (see Chapter 6, Section 6.13) are used and high levels of non-meat materials such as starch, cereal binder, rusk and TVP (see Chapter 6, Section 6.1.4) are found. Flaked TVP is frequently introduced into patties in order to replace meat and fat as a way of reducing cost. The flaked TVP is commonly soaked in water mostly in a ratio of 1:3 (1 part of TVP and 3 parts of cold water) for around 10–15 min in order to hydrate the TVP flakes fully. Hydrated TVP can replace around 20–50% of lean meat in very cheap burgers or patties. Coloured flaked TVP is available in order to match the colour of meat present within

the final product. Another way of utilizing TVP in burgers or patties is to replace only the lean meat with soaked TVP and not to change the fat content of the product. In such cases, as the soaked TVP replaces only lean meat, this is a very economical solution.

Soy concentrates or isolates are frequently utilized within burgers and especially in patties for their contribution towards stabilizing fat as well as increasing firmness of the product, besides their ability to immobilize added water as well. The level applied varies greatly depending on the amount of meat, fat and water present within the recipe. Generally, burgers or patties containing high levels of fat and water can contain between 4% and 6% soy concentrate or isolate. If moderate levels of fat and water are present in the finished product, then 1–2% soy is frequently the level introduced. Some newly developed types of soy isolates can be introduced into the burger mass without being hydrated first with water and such protein displays strong gelling characteristics as well. Soy protein is also regularly introduced as a meat replacement; between 5% and 15% of meat is removed from the recipe and replaced with a soy–water mix prepared in a ratio of 1:4 (1 part of soy such as powdered TVP mixed with 4 parts of cold water). Soy isolate protein also displays an antioxidative effect in burgers as substances within soy isolate such as polyphenolic acids neutralize free fatty-acid radicals. High-gelling soy isolates are utilized to obtain an imitation meat gel of granular nature, which is a mix of soy isolate cut with cold water in the bowl cutter. To produce such granulates, colours such as carmine, fermented rice or caramel are added to water first and are dissolved well; then the high-gelling soy isolate is introduced. The soy:water ratio is around 1:3. After cutting for a short period, a spongy-firm material is obtained which is placed to chill overnight. During placement in the chiller overnight, a meat-coloured firm gel is obtained which can be utilized to imitate lean meat within the burger or patty by being minced with other meat and fat materials. Such a meat imitation is frequently applied in low-cost patties where other fillers are also used in significant amounts.

Starch (see Chapter 6, Section 6.2.2), especially modified and freeze–thaw-stable types of starch, are often added to burgers and patties which have a medium to high level of added water. The level of starch introduced varies between 1% and 5%. Occasionally, antioxidants (see Chapter 6, Section 6.10) such as tocopherol or rosemary extract are applied to delay or avoid rancidity of the product whilst being stored under frozen conditions for a prolonged period of time. Fibres such as wheat fibre (see Chapter 6, Section 6.3) are also utilized since such materials hold moisture during frying or grilling, thus increasing the succulence of the cooked product. Fibres also support immobilization of added water during production of the burger or patty. Sugars are frequently part of a burger or patty as well, owing to their contribution to flavour in balancing the level of salt, as well as supporting the Maillard reaction during frying or grilling. The level of sugar applied varies between 2 and 5 g per kilogram of meat mass. Preservatives such as

SMBS (see Chapter 6, Section 6.4.1) are permitted in some countries such as the UK as additives to raw uncooked burgers or patties sold under chilled conditions (non-frozen). The amount of SMBS introduced into the product is based on the maximum level of sulphur dioxide (SO<sub>2</sub>) permitted in the product to be sold and levels between 300 and 500 ppm of SO<sub>2</sub> per kilogram of mass are generally the maximum permitted level.

Low-fat burgers can lack taste and juiciness when fat replacers are used. In countries such as the USA, carrageenan gels made from ι-carrageenan mixed with calcium ions are used as fat replacers. This blend gives a fairly clear gel which is introduced to the lean-meat mass in order to provide a smoother mouth feel to the product. Other fibre and starch products, as well as modified starches, are also added to imitate a smooth mouth feel to compensate for very low levels of fat.

### 27.3 Manufacturing technology

Beef burgers are commonly produced from fresh beef or semifrozen (tempered) beef which was formerly fully frozen. Food standards in differing countries specify different levels of fat as the maximum permitted levels and meat materials have to be chosen to fall within the set standard (often around 30%). Semifrozen or tempered meat and fat material with a temperature between -10 and -4 °C of 70–75% CL grade is regularly used, resulting in a fat content between 25% and 30% within the finished product. However, combinations of meat exhibiting different levels of fat are commonly processed as well.

One way of producing burgers or patties is to mince semifrozen meat and fat materials with the blade required (e.g. the 3–6 mm blade) to give the particle size desired in the finished product. The minced materials, displaying a temperature between approximately -3 and -1 °C, are then placed in a paddle mixer or any other effective mixing device. When low-value cuts of meat are processed containing elevated levels of connective tissue, the meat material is minced with a smaller blade (such as 2–3 mm) because extraction of protein during mixing is more difficult to achieve. Subzero temperatures of the meat and fat materials will ensure a clean cut during mincing. An attachment to the mincer is commonly used to separate particles of bones and connective tissue from the materials whilst being minced. Only additives such as salt are added to high-quality products but additional additives such as phosphates, spices, fillers, soaked TVP, water and colour are added to lower-quality products. Large amounts of burgers produced simply consist of meat, fat, salt, water and phosphates. All ingredients are mixed well with the minced meat and fat materials until a slight degree of tackiness and shine is obtained and carbon dioxide (CO<sub>2</sub>) is frequently added to the mixed mass during the final stages of mixing to reduce the temperature of the mass to

between approximately  $-3$  and  $-1$  °C for subsequent forming. The low temperatures keep bacterial growth well under control.

The point in time at which additives such as salt and phosphates are introduced to the minced meat and fat materials during mixing has an impact on the consistency and texture of the finished product. If they are added at an early stage during mixing, their addition, in conjunction with mechanical energy introduced via mixing itself, produces elevated levels of activated protein, resulting in a firm-textured product. If additives are introduced at a later stage of mixing, less protein is activated and a loose-textured product is the result. It is quite common to add phosphates first on their own and to mix them for around 30 s, before salt and iced water, as well as other additives, are added. Burgers are generally mixed for less time than patties because consumers commonly prefer a soft or loose texture in a burger compared with a firmer texture in a patty. As stated earlier, the addition of different additives as well as the amount of additives added to the meat mass during mixing depends on the product produced and ranges. Sometimes salt is the only additive introduced. In other cases, up to 25% of water may be added as well as additives such as phosphates, protein, starch, rusk, spices and colour in low-cost patties. The level of fat within the finished product varies from 4% to 30% for beef-based products with 20–25% as an average, whilst pork-based products mostly contain between 25% and 35% fat. Burgers made from mutton commonly contain 20–25% fat as well as spices, water and other flavours. Once again, patties generally contain higher levels of fat than burgers. A patty may contain every possible permitted material at the highest possible level as long as the product holds together during frying or grilling.

Another commonly practised method of producing burgers is to mince semifrozen meat and fat materials with a coarse blade such as 12 mm or  $\frac{1}{2}$  in or to cut such meat and fat materials into cubes which are around 2 cm long, 2 cm wide and 2 cm deep. The coarsely minced materials are placed in the mixer and additives such as phosphate are added. After mixing for around 30 s, salt and a small amount of water are added whilst mixing continuously for another minute. Once the mixed mass displays some degree of tackiness, other ingredients such as spices and soaked TVP (if desired) are introduced and all the ingredients are mixed for a short while more. The mixed mass, exhibiting a temperature from approximately  $-3$  to  $-1$  °C once mixing is completed, is minced once again with a 3–4 mm or  $\frac{1}{8}$  inch blade prior to forming.

If the temperature of the mixed mass prior the second mincing step is too warm, the entire mass is cooled to around  $-2$  °C by the introduction of CO<sub>2</sub>. Large processors of burgers check the fat content of every batch before mixing commences to ensure a constant level of fat within the finished product according to a set recipe or specification. The fact that fat is significantly less expensive than lean muscle tissue is an important reason to maintain a consistent level of fat within the product. A consistent level of fat within the

product also has an impact on forming, texture, succulence, cooking loss during frying and taste of the product.

Forming is occasionally achieved using vertical columns of meat strands, but most often forming takes place horizontally and meat mass is pressed into moulds (sheets of metal or plastic with holes in them), which move back and forth. Once the sheet of plastic or metal is back in the forming machine, the meat mass is pressed downwards, filling the holes within the sheet. Subsequently, the filled sheet moves outwards and the meat mass (formed burger), present within the holes, is knocked out. The thickness of such forming sheets varies generally between 5 and 10 mm, thus determining the thickness and therefore, to a large degree, the weight of the formed product.

In order for forming to be easy and for the burgers to be knocked out of the moulds cleanly, the temperature of the meat mass has to be between approximately  $-3$  and  $-1$  °C since such low temperatures aid forming and knock-out. There is a difference in forming properties when predominately tempered meat which was formerly frozen is used for the preparation of the meat mass, compared with when a mix of frozen and larger levels of chilled meat is used. Because the mass is between approximately  $-2$  and  $0$  °C prior to forming, water present within the mass can change its state from liquid to solid and vice versa, thus influencing the forming properties. As a result, a meat mass containing elevated levels of chilled meat and therefore reduced levels of frozen meat has to be chilled around  $2$  °C lower in order to exhibit the same forming properties as a meat mass containing higher levels of tempered meat which was formerly frozen and less chilled meat.

Very rarely, burgers or patties are produced in the bowl cutter by cutting semifrozen meat and fat materials at a slow knife speed whilst additives such as phosphates, salt, some iced water and fillers are added. The disadvantages of working with a bowl cutter are that a finely cut meat mass without visible meat and fat particles is quickly obtained and that meat and fat particles are not of the same size. The temperature of the meat mass is hard to control when this method is used unless meat and fat materials which are all at the same temperature are processed. Using materials at the same temperature should result in a standardized product with the desired forming properties.

After being knocked out of the forming sheet, the formed product drops on to a belt and travels most commonly through a spiral freezer or tunnel while being exposed to  $\text{CO}_2$  or nitrogen ( $\text{N}_2$ ) for fast freezing. Fast freezing, or individually quick freezing, has the advantage that less damage is done to the muscle fibre owing to the formation with small ice crystals compared with the damage that would be done by large ice crystals obtained during slow freezing at temperatures of around  $-20$  °C (see Chapter 4, Section 4.7). Fast-frozen products should also be thawed rapidly as small ice crystals turn into small droplets of water which can be absorbed by protein and as a result, reduced loss during heat treatment such as frying or grilling is observed.

Occasionally, formed products are sprayed with water before entering the freezing tunnel to prevent the surface from drying during freezing as well as to compensate for loss in weight seen during the freezing process. Freezing by the application of  $N_2$  takes place more quickly and therefore more evenly within the product than freezing with dry ice ( $CO_2$ ) because  $N_2$  demonstrates a temperature of around  $-196^\circ C$  compared with  $-78^\circ C$  in  $CO_2$ . The application of liquid nitrogen freezes a burger within 40–45 s. Furthermore, fast freezing of the product reduces the air pockets commonly seen in burgers or patties. Freezing with  $CO_2$  seems to have some antimicrobial activity, because a small amount of carbonic acid forms on the surface of the formed product during the freezing process.  $CO_2$  reacts with water from the product to form carbonic acid ( $CO_2 + H_2O \rightarrow H_2CO_3$ ), which is a weak acid in chemical terms but still demonstrates antimicrobial properties. During fast freezing, the surface colour of the product can obtain a rather dull appearance and this phenomenon can be counteracted by spraying beef burgers with a water-spray prior to fast freezing.

Occasionally, some manufacturers apply heat originating from infrared heaters on to the formed product shortly before freezing which causes a slight degree of thawing on the surface, thus enhancing appearance, as a very thin layer of free moisture then covers the product, protecting it from the subsequent harsh impact of freezing. On the other hand, a lightening effect caused by fast freezing is desired in burgers and patties made from poultry meat such as chicken or turkey, as a lighter (white)-coloured product is obtained.

Yet another method of obtaining burgers or patties is to fill the minced and mixed meat mass into waterproof or permeable casings and to place long filled logs into the freezer. Once the product is semifrozen, the casing is peeled off and the skinless log is sliced into slices of the same thickness as the diameter of the casing utilized in first determining the size of the product. In burgers produced in this way, a meat content of 85–90% is quite common with added water accounting for around 10%. The remainder is salt, phosphates, spices and occasionally soy protein or even fresh onion. Processes of freezing as well as thawing play a vital role within the production of burgers or patties because meat and fat materials processed generally experience freezing and thawing three times. Firstly, carcass meat is frozen and then tempered for processing. Secondly, the mixed mass is cooled once again to support forming. Thirdly, formed products are frozen again for subsequent storage.

Frozen products such as burgers or patties are frequently vacuum packed. Typically, 12 pieces are placed in a pack containing six double burgers with each double burger being separated by non-stick paper between them. Packing avoids the problem of freezer burn (see Chapter 4, Section 4.8) during storage under frozen conditions as water, present in form of ice within the product, cannot sublime into gas and evaporate. If unpacked products were stored under frozen conditions for prolonged periods of time, freezer burn would result and dry products as well as elevated cooking loss during frying or

grilling would be seen. During freezing, the size of ice crystals within the frozen product increases whilst the number of crystals is reduced at the same time. Growth in crystal size is significantly larger in slow-frozen products during storage than fast-frozen products and more damage is done to the protein, leading to increased cooking loss during thermal treatment such as grilling or frying.

When burgers or patties are not frozen and stored under refrigeration at a temperature between 0 and 4 °C, the product is commonly tray wrapped with a polythene plastic foil to avoid moisture loss. Preservatives such as SMBS (see Chapter 6, Section 6.4.1) extend shelf life and maintain the original meat colour. Non-frozen products are also sold modified atmosphere packed. The atmosphere within the packaging unit contains frequently 70–80% oxygen (O<sub>2</sub>) as well as 20–30% N<sub>2</sub>. High levels of O<sub>2</sub> support the stabilization of red meat colour based on the presence of oxymyoglobin (see Chapter 7, Section 7.1). Having such high levels of O<sub>2</sub> present within the packaging, however, also supports growth of aerobic spoilage bacteria such as *Pseudomonas* spp. and other psychrophilic spoilage bacteria. Therefore, processing meat and fat materials with a very low bacteria count in the first place is vital, together with a very high standard of hygiene during processing itself to achieve the desired shelf life.

Occasionally, a mix of O<sub>2</sub> and CO<sub>2</sub> (20%) is applied in modified-atmosphere-packed products but the introduction of CO<sub>2</sub> can darken the colour of a fresh chilled burger. Therefore, tiny amounts of carbon monoxide (CO) in a modified-atmosphere-packed product are often used (where permitted) with the level of CO being around 0.05% within the packaging. CO displays a high affinity to myoglobin, maintaining a strong red colour over a long period of time. Until now, CO has not been permitted in most countries as it can mislead the consumer respecting the freshness of a product. A meat product can have a fresh colour despite the fact that the very same product can be microbiologically spoiled with high numbers of bacteria.

Because frozen burgers or patties are frequently placed straight on to a grill or fried in a frozen state, the heat treatment is responsible for fast thawing as well as cooking. All possible hazardous microbiological contamination with pathogens has to be eliminated during this single step of heat treatment and overcooking of a burger, or patty, for food-safety reasons is frequently the result. Amines are formed at a higher rate, however, during grilling at high temperatures for a prolonged period of time and amines are carcinogenic. Temperatures of 74 °C in the core of the product are sufficient from a microbiological point of view and repeated turning of the product during grilling speeds up even penetration of heat into the core, thus shortening the time that the product is exposed to high temperatures. Burgers and patties are commonly cooked to a temperature of around 78–80 °C in order to ensure the killing of bacteria such as *Salmonella* spp., *Staphylococcus aureus*, *Listeria monocytogenes* and *Escherichia coli* O157:H7, which is a serious risk in undercooked burgers. At the same time, temperatures up to 80 °C do

not represent a serious risk of overcooking and amine formation. In addition, the presence of small ice crystals in fast-frozen products in conjunction with finely minced particles of fat supports fast transfer of heat into the product during grilling or frying.

The loss in fat during frying or grilling depends greatly on the diameter of the blade utilized during mincing and smaller particles of fat generally exhibit enhanced levels of fat loss as the fat has a larger surface area. Furthermore, when mincing produces smearing of fat (as a result of blunt mincer knives, because of elevated temperatures of the meat mass above 0 °C during mincing, or when knives and blades have not been tightened properly), the fat surface is significantly enlarged, resulting in elevated levels of fat loss during frying. Harder types of fat exhibiting enhanced levels of saturated fatty acids generally demonstrate higher losses during heat treatment than softer fat because softer fat tissue displays higher levels of connective tissue, thus avoiding damage during frying or grilling. Burgers or patties produced from chicken meat are commonly quite low in fat, often with levels below 10%. Chicken fat has a low melting point and thus melts easily during grilling, draining away and causing tiny holes in the cooked product.

A problem in burgers or patties can be a slight touch of pink colour seen in a fully cooked product. Such pinkness can be the result of processing nitrate-containing water or nitrate-containing spices or herbs. This can also be due to the presence of nitrogen dioxide (NO<sub>2</sub>) if products are thermally treated in a direct-fired gas oven where water-soluble by-products such as NO<sub>2</sub> can penetrate into the water in the product. In addition, a phenomenon known as ‘persistent pink’ is occasionally seen in electrically stimulated beef displaying a pH value above 6.1. Within such meat, the iron core of myoglobin is protected against the impact of heat and, even though the product experiences a core temperature of 70–72 °C, the colour within the product is still pink as native myoglobin is maintained. On the other hand, premature browning can occasionally be seen in thinly formed products as oxidation takes place at a rapid speed once the product is defrosted and metmyoglobin, which is brownish-grey in colour, is obtained quickly. The danger here is that the product appears to be fully cooked as it is of grey–brown colour but may have an internal temperature as low as 60 °C. A semicooked product presents a significant microbiological risk.

## 27.4 Summary of critical production issues

- 1 Meat and fat material to be processed should exhibit low bacteria count ( $10^2$ – $10^4$  per gram of product) and no signs of rancidity should be seen in fat.
- 2 An extremely high standard of hygiene should be in place in all steps of production as well as personal (staff) hygiene.

- 3 Water and spices applied to products must not contain nitrite or nitrate as a pink colour will be seen in the product.
- 4 Mincer blades utilized should be sharp and a clean cut should be obtained during mincing.
- 5 CO<sub>2</sub> or N<sub>2</sub> should be introduced to cool the meat mass to around -2 °C prior to forming.
- 6 Individually quick freezing of products and proper packaging should be carried out.
- 7 The packed product should be run through a metal detector.
- 8 The frozen product should be stored at temperatures of around -20 °C.

### 27.5 Crumbed products

Crumbed products are predominantly produced from chicken meat. Chicken protein is relatively easy to activate compared with beef and pork protein as collagen present within chicken is much more fragile owing to the young age (32–35 days) of the animal at slaughter. In the busy lifestyles of consumers nowadays, chicken more than beef and pork fits our no-time society as meat dishes based on chicken can be prepared quickly. Furthermore, chicken meat demonstrates the advantage compared with pork and beef that muscle tissue, and here especially white meat such as breast, is very neutral in flavour, thus accepting almost any added flavour. Chicken meat is divided into light (white) and dark meat. White meat such as breast accounts for around 40% of the carcass and wings around 10%. Dark meat such as thighs accounts for around 35% of the carcass whilst the legs make up around 15%. In summary, around 50% of the carcass is dark meat with white meat accounting for the other 50%.

In most countries, breast meat is the primary choice because of its extremely low fat content once the skin is removed and the fact that a dry product is obtained easily. Dark meat is much more flavoursome and juicy than breast but is often seen as second-grade material because of its darker colour than breast meat as well as the fact that dark meat contains significantly higher levels of intermuscular and intramuscular fat than breast meat. In most countries in the world, proper utilization of dark chicken meat is still a challenge as breast is high in demand with dark meat still being underutilized. Dark or thigh meat also displays a greater tendency towards rancidity over a prolonged period of time than breast meat owing to its elevated level of intramuscular and intermuscular levels of fat.

In the production of crumbed chicken products, high-value meats such as breast are generally minced with a large blade (e.g. 13–20 mm) whilst dark meat is minced with a 4–8 mm blade. The bacterial count of meat to be processed should be between 10<sup>2</sup> and 10<sup>4</sup> per gram of meat. The fat present in dark meat must not display any signs of rancidity as chicken fat is high in unsaturated fatty acids and thus susceptible to developing rancidity quickly.

Chicken skin is a highly valuable material as it is high in connective tissue, thus increasing juiciness in finished products, is rich in flavour and, at the same time, is an inexpensive material. On top of that, the addition of chicken skin, or a skin emulsion, lightens the colour of the finished product as well (whitening effect). Re-formed and crumbed chicken products contain between 0% and 35% chicken skin depending on the quality of the product produced. On the other hand, chicken skin has two disadvantages. Firstly, it is high in fat and therefore prone to rancidity and the connective tissue within fat can disintegrate, or break down, during frying to gelatin and fat, resulting in a spongy texture. To avoid the disadvantage that chicken skin is high in fat, the skin can be turned into an emulsion first in a ratio of 1:4:4 (see Chapter 12, Section 12.2) so that the fat present within and on the skin is well stabilized. Soy isolate protein utilized within the process delays rancidity as soy contains polyphenolic acids which neutralize free fatty-acid radicals. Another way of utilizing chicken skin is to prepare a skin emulsion by soaking skin in a sour solution or by the addition of sour phosphates in conjunction with soy protein, preferably isolate. Most commonly, however, raw untreated chicken skin is used to make chicken burgers. The skin is minced with a blade of 2–3 mm and finely minced skin is introduced into the meat mass during mixing after soy protein has been added. Soy protein also reduces cooking loss during partial or complete frying of the product as it entraps moisture and fat, especially if chicken skin emulsion is part of the recipe. The second problem with chicken skin is a frequently high bacterial count which presents a problem especially in non-heat-treated or partially heat-treated products.

Once all materials to be processed are minced with the respective blade, they are placed in a paddle mixer or any other efficient mixing device. The mixing time of the meat mass has a similar impact on the final product to that described under burgers. Prolonged mixing times together with additives such as salt and phosphates results in a firmer-textured product. On the other hand, late addition of salt in the mixed mass results in a loose-textured product if desired. Salt is normally added at around 0.6–1.0% in formed and crumbed products whilst phosphates are present at 0.2–0.3%. Salt is pro-oxidative, thus speeding up rancidity, but levels up to 1% do not have a significant effect on rancidity. A level of salt around 1%, however, has a major positive impact on the flavour of the product and, when more salt is required in the finished product, additional salt can be introduced into the batter. Additives such as phosphates and salt solubilize protein during the mixing process, thus supporting binding between individual particles of meat. Besides a low pH value in meat processed, high temperatures during processing steps such as mincing and mixing contribute to poor protein extraction. Temperatures between –2 and 0 °C should be maintained as solubility of the actomyosin complex is at its highest within this temperature range.

The mixed meat mass commonly demonstrates a temperature of around –2 °C. If not, the introduction of CO<sub>2</sub> or N<sub>2</sub> is used to reduce the temperature

of the meat mass to around  $-2\text{ }^{\circ}\text{C}$  to ensure consistent forming to the desired weight and shape.  $\text{N}_2$ , owing its greater cooling capacity, cools the meat mass more quickly and more evenly than  $\text{CO}_2$  does. However, care has to be taken that the application of  $\text{N}_2$  is carefully controlled since it can cause a drop in temperature within the mixed meat mass greatly below the desired level. It is then almost impossible to raise the temperature again within the meat mass without inflicting a major negative impact on the quality of the finished product. Nowadays, a cryogenic gas such as  $\text{CO}_2$  or  $\text{N}_2$  is introduced into the mixing device from the bottom as, when it is introduced from the top, much injected gas is lost before it even reaches the meat mass. Having said that, overuse of cryogenic gas should be avoided to obtain a temperature around  $-2\text{ }^{\circ}\text{C}$  as a certain amount of protein and therefore binding capacity are lost under the impact of such low-temperature methods. In addition, excess introduction of  $\text{CO}_2$  frequently causes the formation of pores within the formed product as  $\text{CO}_2$  is not an inert gas, thus reacting with other material within the meat mass. Entrapped  $\text{CO}_2$  literally explodes under the impact of heat during frying or other forms of heat treatment, thus causing formation of pores. All  $\text{CO}_2$  must be removed before forming takes place. Creating a vacuum during forming is of great help in removing  $\text{CO}_2$  from the meat mass. Furthermore, excess levels of carbonic acid are obtained as a result of the introduction of high levels of  $\text{CO}_2$  into the meat mass as the  $\text{CO}_2$  reacts with water from meat itself ( $\text{CO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{CO}_3$ ), thus supporting formation of pores especially if high levels of unstabilized chicken skin are present within the meat mass. Formation of pores is significantly reduced with  $\text{N}_2$  because it is an inert gas that does not react with anything within the meat mass itself.

Temperatures of the meat mass to be formed should not be below  $-3\text{ }^{\circ}\text{C}$  as temperatures below this level have a negative impact on the adhesion of the batter afterwards as well as making forming itself more difficult. In addition, at temperatures below  $-3\text{ }^{\circ}\text{C}$ , owing to the commonly low level of salt present within the product (around 0.4–1%), the freezing point of intramuscular water is between approximately  $-2.5$  and  $-3\text{ }^{\circ}\text{C}$ . The water present does turn into ice, which prevents protein from being solubilized, negatively affecting the binding between the particles of meat. Binding between individual pieces of meat within the formed product can be enhanced by mincing meat materials with a smaller blade, thus increasing the surface area for better protein activation. Mincing meat with a smaller blade, however, takes away the meaty chunky bite of a reformed product.

Temperatures above  $0\text{ }^{\circ}\text{C}$  affect forming and especially knock-out properties in a negative way as the meat mass is simply too warm to be cleanly formed and afterwards knocked out of the forming plate. At temperatures above  $0\text{ }^{\circ}\text{C}$ , a product poor in binding quality will be placed on the belt going down the batter line. The temperature within processing areas where mixing and forming occur is generally around  $1$ – $8\text{ }^{\circ}\text{C}$  in order to maintain a low temperature during forming of the mixed meat mass.

Some formed chicken products are also produced in the bowl cutter by obtaining an emulsion first from fatty trimmings, chicken skin, some iced water, phosphate and salt as well as soy isolate and starch. Such an emulsion is introduced into the final mass between 5% and 40% and chicken MDM is subsequently cut into the emulsion at a medium-fast speed. Semifrozen thigh meat is finally added and is cut at a slow speed for a short period to improve overall appearance. As semifrozen chicken skin as well as semifrozen fatty trimmings are processed in conjunction with iced water and semifrozen MDM, the temperature of the emulsion including the visible thigh meat (also semifrozen) is usually maintained at around  $-2^{\circ}\text{C}$  and no  $\text{CO}_2$  is required prior to forming of the meat mass.

Once the product is formed, usually through the use of forming machines as described under the manufacture of burgers (meat mass is filled into holes within the forming sheet by being knocked out afterwards), coating systems commonly apply wheat flour as predust. Other high-amylose starches (potato) are also occasionally applied as they help to form a suitable texture in the finished product. Coated products commonly have several layers of coating attached to the actual meat mass and all layers within the total coating must stick together well. Most commonly, three layers are applied which are predust, batter and finally the breading itself. The coating systems can account for up to 30–35% in skin-on products such as chicken leg and around 15–20% in skinless formed products, an important cost factor in itself because the coating is made up of inexpensive materials. However, thicker coating systems applied generally result in elevated levels of oil pick-up during frying which is not always desired.

Potato starch within the predust is known to improve adhesion of the batter. Hence, starches high in amylose cause more crispy products to take up less fat, or oil, during frying, which results in a more crispy and less soggy (greasy) product. Predust such as wheat flour has to support binding and adhesion of the other layers and wheat-based products are often applied since gluten (see Chapter 6, Section 6.1.3) performs very well, being a highly gummy and gluey type of protein. Soy protein at around 1–3% is occasionally introduced into the predust also to support the adhesion of batter and crumbs to the product itself. The introduction of predust also aids gain in weight during frying, thus reducing the cost of the product. Flavours or spices are frequently part of the predust as well. Application of a predust is especially important in fully cooked formed products to support adhesion of all layers applied to meat during frying or other forms of heat treatment. Without a predust, adhesion from batter and crumbs on to the product is weakened, causing the well-known but undesired blow-away effect or separation of the coating from meat.

A batter is a liquid material commonly consisting of water, starch, flour, spices or seasonings as well as materials such as guar or xanthan gum creating some degree of viscosity to obtain a runny and yet slightly viscous mass evenly covering the formed and pre-dusted product. The level of viscosity

greatly determines the uptake and run-off from batter once applied to the formed product with more viscous materials resulting in less run-off, thus creating a thicker layer of batter on the product. The thickness of the batter layer has to be fine tuned according to the product produced. Typically, the liquid batter runs through a device where finally a thin wall, or curtain, of batter runs down over the formed or even non-formed products such as chicken breast. Afterwards, some sort of fan blows over the battered product to remove excess liquid which runs back to the original batter container and is recycled.

Crumbs form the last layer of the coating and are applied to the battered product. Quite a few different types of crumb are on the market, varying in particle size, colour with some even containing spices or flavourings. Occasionally, predest and batter are applied in one step in liquid form but adhesion of the entire coating system on the product will ultimately suffer, as predest in the form of flour, being the connecting link between coating and meat itself, is simply missing.

During subsequent frying of the battered and crumbed product, around 5–12% of the frying oil is taken up. Oil pick-up during frying can be reduced and this is in constant demand because low-fat fried products are desired by consumers nowadays. Spraying of the crumbed products with an emulsion made from water, oil and soy protein prior to being fried reduces uptake of oil during frying. A particular problem in coated and cooked formed meat products is the occasional splitting, or cracking, of the coating which is primarily caused either by the presence of CO<sub>2</sub> (therefore overuse must be avoided during cooling of the meat mass prior to forming) within the formed product or uneven layers of batter present on the surface of the product before being crumbed, thus creating areas that demonstrate a very thin layer of batter. The oil utilized displaying high temperatures above 180 °C can also aid cracking of the coating. Pinking in crumbed or formed chicken products must be avoided and sources of accidental nitrate or nitrite contamination can be materials such as water or spices. Tiny amounts of nitrite (around 3–5 ppm) are sufficient to cause a pinkish touch. Spray-dried soy protein can be a potential source of nitrite as well. In addition, CO obtained by operating equipment with natural gas can cause unwanted pinking of products as well.

Once the formed product is predested, battered and crumbed, thermal treatment is the next processing step. However, a small proportion of crumbed products are sold uncooked and are individually quick frozen after being crumbed. Coated products are commonly either par fried or flash fried in frying oil for 20–30 s by temperatures between 170 and 180 °C, fully cooked in frying oil or flash fried in oil and subsequently fully cooked with dry heat only or a combination of steam with dry heat being an additional option. Chicken burgers are commonly formed, battered, breaded and fried up to the desired core temperature. Within flash frying, the coated product travels through an oil bath for the setting, or fixation, of the coating system before

being individually quick frozen whilst the core of the product remains largely uncooked. Some products are fully cooked in hot oil but high levels of oil are absorbed during the process as the coated product passes through the oil bath at a slow speed, determined by the size of the piece of meat as well as the desired core temperatures to be obtained. In addition, such high-in-fat products exhibit reduced juiciness once reheated. When cooking with oil, the coated product passes through an in-line tunnel, which is basically an oil bath, and placed on a grid belt to travel through the tunnel. The disadvantages of an in-line tunnel are that only one set temperature (temperature of the oil) can be applied to the product and that the tunnel is restricted in length. As a result, the temperature of the oil is set slightly above the temperature required in order to ensure that all products are sufficiently cooked (avoidance of undercooking), thus generally resulting in a slight degree of overcooking. Elevated temperatures can also cause the coating to separate from the meat mass as internal moisture penetrates to the surface which can also result in sogginess of the coating itself. Hence, elevated oil temperatures reduce pick-up, thus lowering the cooking yield of the product.

The appearance of smoke indicates that the temperature of the oil is too high, and oil absorbed by products during frying has to be replaced on a regular basis. Despite the addition of fresh oil on a frequent basis, all the oil has to be replaced occasionally as rancidity (the amount of free fatty acids) develops over time up to an unacceptable level, with the maximum level being specified as not more than 2–3% of oleic acid within the frying oil.

Another method of cooking is the utilization of convection ovens and modern equipment can even introduce steam, thus providing the option of cooking with dry heat or moisture only or a combination of dry heat and moisture. Some degree of moisture during cooking increases cooking yields, resulting in a juicier final product. During cooking, core temperatures obtained in chicken products vary based on the set standard and core temperatures around 74–76 °C are commonly required. Modern double-zone spiral cooking ovens display greatly increased belt length, thus allowing the product to be cooked at lower temperatures up to a set core temperature, which results in an increased cooking yield. Cooking at lower temperatures but for a prolonged period of time also ensures that heat is evenly distributed within the product to be cooked. Convection cooking is at such an advanced state nowadays that the long-practised method of coating the formed product first followed by flash frying prior to cooking will soon no longer be practised. By working with highly sophisticated convection ovens the product is first cooked and then passes the processing steps of coating and flash drying, thus resulting in very juicy products with high cooking yields.

In addition, par frying or flash frying as such may soon be obsolete as processes such as infrared heating could replace this processing step. Thermal treatment with microwaves is a subject of intensive research; microwaves turn electric energy into electromagnetic energy, which causes friction between molecules of water within the product as a result of reversal of polarity,

leading to an increase in temperature. Microwaves penetrate into solid matter at a fast rate which can be seen every day by defrosting or reheating of food in a microwave oven.

Fully rather than partially cooking products is generally the preferred method as fully cooking products, compared with flash frying only, reduces the risk of consumption of undercooked products in general. In addition, fully cooked food is microbiologically more stable than semicooked food and factors such as distribution and storage are easier. Fully cooked and frozen products can be stored for months, thus allowing easy coverage of subsequent peaks of demand. Following thermal treatment, the partially or fully cooked product is individually quick frozen primarily by the application of CO<sub>2</sub>, packed into cartons, passed through a metal detector, placed on pallets and stored at temperatures around -20 °C.

## 28

# Typical patty and nugget products from around the world

### 28.1 Beef patty

Beef patties of greatly differing levels of quality are produced. A typical recipe of medium to high quality would include 55–60% beef of 85% CL grade and 40% beef of 50% CL grade. 8–10% water is added as well as 0.3–0.5% salt and 0.2% phosphate. Commonly, soy protein is also introduced at around 1% to stabilize fat during frying. Flavour or spices are frequently part of the recipe as well. Semifrozen meat and fat materials are commonly minced with a coarse blade (20 mm) first before being placed into a mixing machine. Salt, spices (pepper, garlic and onion) and phosphate are added and all ingredients mixed for around 30 s. Iced water and soy protein are added and mixed continuously for around 2 min. At this stage, some degree of tackiness and shine is seen within and on the mixed meat mass. The tacky meat mass is subsequently minced with the desired blade (3–4 mm) and cooled with the help of carbon dioxide (CO<sub>2</sub>) to around –2 °C prior to forming for a clean knock-out. Occasionally, the temperature of the mixed mass prior to the second mincing is around –4 °C and a temperature of around –2 °C is obtained after mincing. As a result, the introduction of CO<sub>2</sub> prior to forming is not required. The formed product is IQF frozen, packed into bags with a predetermined number of patties and most often vacuum packed. Bags are placed into cartons and the product is stored at temperatures of around –20 °C.

### 28.2 Chicken patty

Chicken patties are also produced in vastly differing levels of quality. A medium-quality chicken patty would contain 20% chicken skin, 15% iced

water, 30% chicken thigh meat, 30% chicken breast meat as well as around 2–3% soy protein and 2% starch. Salt is added at 0.7–1.0% in the finished product as well as phosphate at around 0.3%. Commonly, spices are part of the recipe as well. The slightly frozen chicken skin is minced with the 2–3 mm blade whilst thigh meat is minced with the 8–10 mm blade. The high-value breast meat is minced with the 13 mm blade. All well-chilled and slightly frozen materials are placed in the mixing device and mixing commences by the addition of phosphates, salt, soy protein and spices for around 30 s. Iced water is introduced and mixing is continuous for around 2 min. Starch is added and after mixing for a further minute the process is completed. CO<sub>2</sub> is introduced in the final stages of mixing to reduce the temperature to around –2 °C prior to the product being formed. The formed product is subsequently individually quick frozen, packed into cartons and stored at temperatures of around –20 °C.

### **28.3 Chicken nuggets (high quality)**

High-quality chicken nuggets are produced from around 80–85% semifrozen breast meat which is minced with the 13 mm blade. Semifrozen chicken skin is minced with the 2–3 mm blade and 5–10% of such minced chicken skin is added to coarsely minced breast meat. All is placed in a mixing device and salt is introduced at 4–8 g per kilogram of meat mass as well as phosphate at 3–4 g per kilogram of meat mass. Mixing occurs for around 30 s before iced water is introduced at 5–8% and all ingredients are mixed for around 2 min until a tacky mass is obtained. Most commonly, the temperatures of the meat and skin material processed are optimized in a way that a temperature of around –2 °C is obtained once mixing is completed. When elevated temperatures around or above 0 °C are seen within the mixed meat mass, CO<sub>2</sub> is introduced during the final stages of mixing to obtain a temperature of around –2 °C for subsequent forming. The formed product drops on to a belt; prebatter, batter and coating (crumbs) are applied and then either the crumbed product is flash fried in oil for around 30 s at 170–180 °C and afterwards individually quick frozen or, more commonly, the flash-fried product is fully cooked by the impact of dry heat or a combination of dry and moist heat before being individually quick frozen. Some products are also fully cooked in oil before being individually quick frozen.

### **28.4 Chicken nuggets (low cost)**

A typical recipe for low-cost chicken nuggets would contain 30% chicken skin (minced with the 2–3 mm blade), 20% MDM, 20% water, 20% minced thigh meat (6–8 mm blade), 2–3% soy protein and 5–6% starch. Salt is

applied at around 1%, phosphates at 0.3–0.4% as well as flavouring. The total mass can be obtained by mixing all materials for around 3–4 min until a tacky mass is obtained, but another option is to create an emulsion first in the bowl cutter from chicken skin, MDM, iced water and all additives. Minced thigh meat is just gently mixed into the fine paste within a mixing device and CO<sub>2</sub> is applied to reduce the temperature of the mixed mass to around –3 °C prior to forming. Following forming, the individual layers of pre-dust, batter and crumbs are applied and the crumbed product is flash fried, or flash-fried and fully cooked by the impact of dry heat, or fully cooked in oil itself.

## 29

### **Sliceable and non-sliceable blood sausage**

Sliceable and non-sliceable blood sausage are the kinds of product acceptable to consumers in some countries but not in others. Generally, such products consist of inexpensive raw materials predominantly originating from pork such as meat from shoulder, PHM, jowls, pork skin and, of course, blood. The utilization of such inexpensive raw materials often first arose in times of war, or during other times of need, when no part of an animal was thrown away once it had been slaughtered and highly nutritional products were made from by-products. Blood-containing products can be divided into sliceable and non-sliceable products and the level of blood within the product varies from 5% to 60%. A large percentage of sliceable blood sausage is consumed cold whilst most non-sliceable products are predominately eaten hot.

#### **29.1 Selection and preparation of raw materials**

Sliceable blood sausage commonly contains materials such as cooked ham as the visible particles, or show-meat, within the product. Generally, ham is produced in the first place from skin and boneless lean pork shoulder or leg meat; the meat is injected at around 30–40%, tumbled and steam cooked in a fibrous or waterproof casing (see Chapter 8). However, any other type of ham can be utilized as well. The chilled ham is subsequently cut into cubes of various sizes from 5 mm up to 3 cm. Other types of sliceable blood sausage contain precured and precooked meat of 75–90% CL grade or PHM, which also has been precured and precooked as described in Chapter 25, Section 25.1. Chilled PHM is generally cut into cubes or minced with the 13–20 mm blade. Occasionally, the very fatty parts of PHM are removed

prior to further processing for blood sausage as large pieces of fat within the product are not appealing to the consumer. The removed fatty trimmings can be utilized for the production of fine liver sausage so that nothing is wasted.

Another frequently processed raw material for sliceable blood sausage is cured and cooked tongue originating from beef or pork. Pork tongues are placed in a salt–nitrite soaking brine containing around 10% salt for several days for curing purposes whilst beef tongues, owing to their size and thickness, are often injected first before being placed in soaking brine for 1–2 days as soaking only would require a significantly prolonged period of time for a beef tongue to be properly cured. A soaking or injection brine contains around 8–10% salt as well 800–1000 ppm of nitrite per litre. When processing tongues it is important that the outermost layers of the tongue are removed prior to soaking or injection and this is achieved by placing beef tongues for a short period of time into water at 80–90 °C. As a result, the outer layer on the surface of the tongue separates and can be easily removed. Pork tongues are ‘cleaned’ in machines with a rapidly rotating barrel. Under the impact of warm water as well as by being scraped by baffles present inside the fast rotating barrel, the outer layer on pork tongues is effectively removed.

Basically, all materials utilized for show-meat in sliceable blood sausage must be of sufficiently good quality and microbiological status that they could be consumed on their own without any hesitation. It must not be the case that ‘leftover’ products, already displaying signs of sliminess, off-flavour or discolouration, are utilized as raw materials rather than wasting them. In summary, all visible meat materials further processed for sliceable blood sausage are cured and cooked before being cubed, diced or minced. For sliceable as well as non-sliceable blood sausage, small cubes of fat are commonly introduced as they provide a nice contrast to the generally dark-coloured product and fat is also an inexpensive raw material in its own right. The cubes of fat are cut from back fat as this type of fat is hard in texture owing to its low content of unsaturated fatty acids.

### **29.1.1 Treatment and use of cooked pork skin**

Cooked pork skin is the material that provides sliceability to cold-consumed sliceable blood sausage and also adds firmness to non-sliceable products. Its functional properties arise because the collagen present in pork skin at high levels turns into gelatin during moist heat treatment, which forms a gel upon cooling. Pork skin to be processed should exhibit a low bacteria count and fresh chilled skin which has never been frozen displays superior technological qualities to skin which was previously frozen. Pork skin to be processed should be well defatted and no hairs should be left on the skin either. Areas of skin showing spots of blood as a result of, for example, poor handling during the slaughtering process should be removed and skin from the loin area is generally the preferred choice. Differently coloured stamps applied to a pig carcass (skin) during veterinary inspection after the slaughtering process

should be removed (cut out) as well. Skin from young pigs aged 5–6 months is the preferred choice compared with skin from sows because the skin from sows is significantly thicker and thus much harder to precook. The increased age of the animal (sow) results in a significantly higher number of cross-links within collagen molecules and thus a tighter collagen structure. Skin from young pigs contains collagen which is of much softer texture and can be precooked easily as the degree of swelling during moist thermal treatment depends largely on the number of cross-links within the collagen molecule (the fewer the number of cross-links, the greater is the degree of swelling (see Chapter 1, Section 1.3). Collagen firstly shrinks by the impact of moist heat at around 65 °C before being softened by temperatures of 80–85 °C. Continuous moist heat treatment causes collagen to swell and finally turn into gelatin (see Chapter 25, Section 25.3).

Pork skin is thermally treated either with steam or in a hot-water bath until a texture is obtained whereby if the skin is pressed with two fingers, the fingers pass through the skin quite easily. Undercooking of skin results in a firm-finished product whilst overcooking reduces firmness because elevated levels of procollagen are obtained, which does not form a gel upon cooling. Cooked pork skin is predominantly processed while it is still hot when producing sliceable as well as non-sliceable blood sausage.

### **29.1.2 Treatment and use of blood**

Blood is a highly valuable raw material but, at the same time, very sensitive to handle. The  $A_w$  of blood is extremely high at around 0.99 and the pH value is around 7.3–7.5. Both of those factors favour bacterial growth immensely. After collection of blood, anticoagulation agents such as TSC are added to avoid coagulation. Blood can be stored for 2–4 days at around 1 °C with freezing being another option. The bacteria count of blood should not exceed  $10^4$  per millilitre of blood. The addition of salt, or even nitrite, is not a significant hurdle against microbiological growth and the combination of high  $A_w$  as well as pH value makes blood highly perishable. Therefore the collection of blood during bleeding of the animal has to occur in a very hygienic way. In addition, blood has to be cooled quickly afterwards to a temperature below 3 °C, as applying low temperatures is the only effective hurdle against spoilage.

The addition of salt does not have much impact regarding extending shelf life of blood as the  $A_w$  will not be lowered to a level of 0.95 which would introduce an effective hurdle against Enterobacteriaceae. When nitrite is added to blood a large amount of added nitrite is oxidized to nitrate by oxidase enzymes and nitrate does not exhibit a hurdle against microbiological growth. Nitrate would need to be reduced again to nitrite in order to be an effective hurdle against bacterial growth. As blood is stored at temperatures below 4 °C and the enzyme nitrate reductase, which would reduce nitrate to nitrite, does not work at temperatures below 8 °C, negligible amounts of

nitrate are reduced to nitrite. For the same reason, presalting of blood with salt and especially nitrite to obtain a better and stronger curing colour within the finished product does not help either because, as mentioned above, nitrite is oxidized to nitrate and therefore does not support the formation of nitrosohaemoglobin.

For sliceable cold-consumed blood sausage and for most non-sliceable products as well, pork blood is the preferred choice owing to its nice red colour compared with the dark and even blackish colour of beef blood. The different intensities and variations in red colour within blood are primarily caused by different concentrations of haemoglobin present within blood from different animals. As stated, blood from beef is darker than blood originating from pork as beef is generally significantly older than pigs at the point of slaughter. Most commonly, pigs are slaughtered at an age of around 5.5–6 months whilst bulls are around 2 years of age at the point of slaughter. Hence, cows are slaughtered at a much more advanced age, thus resulting in an almost black colour from cow blood. Furthermore, the bodies of cattle are much larger and cattle also move around more than pigs during their lifetime. Elevated levels of oxygen have to be transported through the bodies of the animals every day by haemoglobin, the carrier of oxygen; thus blood from cattle demonstrates higher levels of haemoglobin than the blood from pigs. Blood in general contains between 90 and 120 g of haemoglobin per kilogram of blood. Muscle tissue of pork contains around 1 g of haemoglobin per kilogram of tissue whilst muscle tissue from beef displays around 4–5 g of haemoglobin per kilogram of muscle tissue. In addition, the amount of haemoglobin present in muscle tissue depends to a large degree on the efficiency of the bleeding process during slaughter.

## 29.2 Selection of additives

The number of additives applied in blood sausage is quite limited as processes such as activation of muscular protein and emulsification of fat and water are not of importance. As a result, additives such as phosphates, added proteins, carrageenan, colours and starch are generally not utilized. Salt is present at around 1.6–2.2%, with sliceable products containing generally slightly more salt than non-sliceable products. Salt fulfils the sole function of contributing to flavour as no reduction in  $A_w$  takes place because the level of free water, also originating from the addition of blood, is always very high. Nitrite (see Chapter 7, Section 7.2) is applied to obtain curing colour in blood based on the formation of nitrosohaemoglobin instead of nitrosomyoglobin as formed in countless other meat products by nitrite reacting with myoglobin within muscle tissue. Nitrite is also applied during precuring of materials such as tongues and PHM to obtain cured precooked materials. For a better colour development in sliceable products, the pH value of blood is frequently reduced to around 5.9–6.0 by the addition of citric acid at levels around 0.4–0.5% as

1 g of citric acid reduces the pH value per kilogram of blood by around 0.2–0.3 pH units. At such pH levels, some degree of undissociated nitrous acid ( $\text{HNO}_2$ ) is obtained (see Chapter 7, Section 7.3), releasing nitric oxide (NO) to bind with haemoglobin to form nitrosohaemoglobin thus supporting curing colour in blood. The addition of ascorbic acid, or ascorbate, on the contrary, results in poor colour because ascorbic acid binds oxygen, thus reducing the level of oxyhaemoglobin within blood and at the same time increasing the level of unwanted methaemoglobin. Spices and herbs are introduced to taste for example pepper, onion, marjoram, cinnamon, pimento, thyme, cloves and nutmeg are frequently applied. The addition of milk, fried onions (containing high levels of pyruvic acid) as well as spices such as thyme, coriander and marjoram, however, can have a negative impact on colour in the finished sliceable product as the amount of blood added is only around 5–8% and therefore a significant quantity of the nitrosohaemoglobin in the blood might be discoloured. Spice extracts can be applied so that these problems are not encountered. In non-sliceable products such as black pudding, materials such as rusk (in the UK) as well as cooked materials such as barley, rice and cubed potatoes are introduced. Fresh chopped onions are also commonly fried in oil before being added to non-sliceable products. Most non-sliceable products have a dark colour as the amount of blood added is high (30–60%). Since these products have a large amount of added blood, the fact that pyruvic acid might reduce the amount of nitrosohaemoglobin is not important, as the large amount of blood ensures the final dark colour of the product anyway.

### **29.3 Manufacturing technology for sliceable blood sausage**

Sliceable blood sausages are commonly produced from visible particles of fat, precured cooked meats such as PHM or lean trimmings (shank) or cooked ham products. All the ingredients are held together by a finely cut mass which consists of cooked pork skin, hot water (or broth) and blood. Cooked ham utilized as visible particles or show-meat is diced into cubes ranging from 5 to 30 mm in size whilst cured and cooked meat materials such as PHM or meat from shanks are minced with the 8–13 mm blade. The same material can be diced into small cubes as well. Cured and cooked tongues of both beef and pork are generally cut into smaller pieces whilst some pork cooked tongues are utilized as a whole piece as well. All cubed, diced or minced meat or tongue materials are thoroughly washed with hot water (80–90 °C) and left to drain so that the meat materials in the finished product will be clearly visible without traces of protein or fat attached to them. Washing of those materials with hot water also serves the important technological function of raising the temperature as a warm total mass has to be obtained.

Pork back fat is cut into small cubes of 4–5 mm size which are blanched in hot water. Blanching of fat cubes at 90–95 °C causes fat to melt and to be removed from the opened fat cells present on the surface of the fat cube as the shrinking collagen closes the cell that has been cut open. As a result of being 'closed', blood does not penetrate afterwards into the cube of fat which remains white in colour. Blanching of fat cubes lasts for around 5 min and the shrinking of cell walls made from collagen results in a spongy-firm texture in the blanched cubes of fat. The non-penetration of blood into the fat cube as a result of proper blanching and therefore maintaining a white-coloured cube of fat is primarily of importance whilst the mixed sausage mass has not yet been thermally treated. Blood-coloured fat cubes within the finished product can also be the result of undercooking the finished product, causing insufficiently denatured haemoglobin to penetrate into fat cubes during storage of the product.

Once meat and fat materials to be further processed have been washed with hot water and left to drain, all the materials are placed in a mixing device whilst still warm. The cooked pork skin is removed from the hot-water bath or taken out of the steam treatment and placed straight into the bowl cutter or into a container. If the cooked pork skin cannot be processed immediately, which should be avoided if possible, it should be covered in hot water (at least 90 °C). When a small amount of hot skin material is to be processed in the bowl cutter, prewarming of the bowl by placing hot water into the cutter (which is subsequently removed before hot skin is placed into the bowl cutter) is advantageous as a cold bowl cutter would absorb much heat from hot pork skin, making obtaining a finely cut, smooth and creamy skin material with a high temperature less likely.

The hot pork skin is cut at a high knife speed, and hot broth or just hot water at a temperature of around 90 °C or above is added. Hot water or the broth in which the skin was cooked in the first place is added gradually to the finely cut skin whilst cutting at a high knife speed in an amount so that 120–130% yield is obtained. To be more specific, if the weight of pork skin prior to moist heat treatment were 100 kg, hot water or broth would be added afterwards at an amount so that the result was 120–130 kg of finely cut skin mass. As a rule of thumb, the amount of hot broth or hot water added to the cooked skin whilst being cut at a high knife speed into the bowl cutter depends largely on the desired firmness of the skin mass within the finished product, with lower addition rates creating a more highly viscous skin mass, which results in a firm finished product. On the other hand, elevated levels of added hot water or hot broth result in a less viscous skin mass and the final product will be less firm. Practical experience demonstrates quickly the exact amount of water or broth to be added to achieve the optimal firmness of skin mass in the final product.

The addition of broth can create a problem in the finished product when a large amount of fat is attached to the precooked skin and elevated levels of fat within broth are added to the already fatty skin mass. There might be

visible separation of the fat within the skin–blood mixture once the product is thermally treated and cooled, and the cooked and chilled blood–skin mass might have a crumbly texture. However, a small degree of fat within the skin mass is not a disadvantage as it gives a certain degree of shine to the finely cut and hot skin mass. In general, if pork skin is processed with little or preferably no fat attached to it, the addition of broth does not cause a problem. Despite this, however, some manufacturers prefer to add hot water instead of broth.

The process of obtaining the skin mass is completed once a fine-cut, runny and yet viscous hot mass is obtained. Blood can be added directly to the finely cut mass of cooked pork skin but the temperature must be below 60 °C as haemoglobin would be denatured at temperatures above 60 °C, resulting in a grey-coloured finished product. A temperature of around 55–60 °C can be achieved through the addition of some ice once the desired creaminess of the skin mass is obtained after a reasonable period of cutting at a high knife speed. Once blood is added into the skin mass, all the material is cut for a while at a medium–high to high knife speed just to ensure an even distribution of blood within the skin mass as well as the introduction of oxygen into the skin mass.

The addition of blood directly into the skin mass has the advantage that high levels of oxygen are introduced into the skin–blood mass, creating a high quantity of oxyhaemoglobin. Oxyhaemoglobin is chiefly responsible for the colour in sliceable blood sausage as the level of nitrite introduced is insufficient to convert all haemoglobin present within blood into nitrosohaemoglobin (high levels of nitrite would be required which would result in levels of residual nitrite above the legal limit). Therefore, it is desirable to create as much oxyhaemoglobin as possible as it is predominantly responsible for the colour in the finished product. Cutting of the skin–blood mass must not take place under vacuum as the application of vacuum removes oxygen, thus creating high levels of methaemoglobin which result in a grey-coloured finished product. The amount of blood added to the skin depends on the desired colour of the blood–skin mass, with higher levels of blood darkening the colour. If the finished product contains 30% of blood–skin material, adding 20% blood to the hot skin during cutting results in around 6% blood in the finished product, which gives the product an attractive red colour. Levels of blood between 5% and 8% in the finished product are mostly aimed for.

The disadvantage of adding blood directly to the skin mass is that the mixture has to be cooled first below 60 °C to avoid denaturation of haemoglobin. The temperature of the overall mass, consisting of the skin–blood mass as well as warm cubed (minced) meat and fat materials as well as blanched cubes of fat, is then quite low once all the ingredients have been gently mixed. Obtaining a low temperature within the total mass before filling into casings greatly increases viscosity, thus making filling more complicated.

Upon completion of the preparation of the skin–blood mass, the material is added to warm, washed and drained cubed tongues, PHM and blanched pork back fat at around 30% of the total weight. As a result, the total mass consists of around 30–35% blood–skin mass whilst tongues, PHM and blanched cubes of fat account for around 65–70%. The mixture is then well mixed with the introduction of spices, herbs, salt and nitrite because materials such as blanched fat cubes, blood and skin mass have not had any salt added to them up to that point.

The other commonly applied method of manufacturing sliceable blood sausage is to cut the hot skin on its own with hot water, or broth, until the desired level of viscosity is obtained without the addition of blood. Within this method, around 25% of the finely cut and hot skin mass is added to warm, washed and drained cubed (minced) meat and fat materials and all ingredients are mixed well. After mixing for a short while, blood (6–8% of the total mass) and spices are introduced and all the ingredients are mixed continuously until all the blood has been evenly introduced. At the end of the mixing process, salt and nitrite are added to obtain the desired level (the salt is never added to the hot skin mass whilst it is being cut in the bowl cutter). This method of adding blood to the overall mass during mixing instead of to the skin mass whilst being cut in the bowl cutter generally results in a higher final temperature of the finished mixed mass as no reduction in temperature below 60 °C within the skin mass is required. Therefore filling is easier as the sausage mass is less viscous as a result of the elevated temperature. In this method, blood is commonly whisked intensively on its own for a short while before being added to the sausage mass to introduce high levels of oxygen. It is also commonly prewarmed by placing the bucket, or pail, containing blood into warm water whilst being whisked in order not to reduce the temperature of the total mass significantly through the addition of 6–8% cold blood to the total mass. Frequently, blood is also left standing for a while at room temperature before being whisked or intensively stirred prior to the addition to the sausage mass.

In both methods, the amount of visible particles such as PHM, cubed ham, fat and others within the total mass should be more than 60% to avoid an uneven distribution of the visible particles within the total mass after thermal treatment of the product. If there are 60% or more visible (solid) particles in the liquid skin–blood mixture, gravity does not cause the visible particles to separate from the blood–skin mixture during thermal treatment and subsequent cooling. The solid particles remain in contact with each other within the total mass and the liquid blood–skin mass fills up the gaps in between the particles. If there are fewer than 60% solid particles in the total mass, the solid particles separate from one another during thermal treatment and distinct layers of particles and blood–skin mixture will be seen in the final product. This can be explained by the fact that, as the viscosity of the blood–skin mixture becomes very low (as it reaches 70 °C or higher) during thermal treatment, solid particles (which are not stabilized any longer in the skin mass now that its viscosity is low) settle to the bottom of the casing as a result of gravity.

Furthermore, mixing of the mass in both methods must not take place under the impact of vacuum as high levels of methaemoglobin would be created, supporting a dark and grey colour in the finished product. Oxygen ( $O_2$ ) should rather be introduced during mixing without the application of vacuum, thus supporting the formation of oxyhaemoglobin. The colour obtained in the finished product in sliceable blood sausage is always caused by the mixture of nitrosohaemoglobin, methaemoglobin and oxyhaemoglobin, with nitrosohaemoglobin and especially oxyhaemoglobin being chiefly responsible for the required red colour, thus keeping the level of methaemoglobin as low as possible. Oxyhaemoglobin is a light-red colour, methaemoglobin is brownish-grey whilst nitrosohaemoglobin is red in colour.

Once the mixed mass is obtained, filling into predominantly waterproof casings but also natural casings such as pork stomachs should take place without delay for several reasons. Firstly, the mixed sausage mass is high in free water and countless nutrients such as protein and displays a high temperature as well. All these criteria favour bacterial growth and a rapid increase in numbers can be seen when long delays occur between obtaining the sausage mass and thermal treatment. Secondly, the level of oxyhaemoglobin is gradually reduced during long periods of delay which is beneficial for the formation of methaemoglobin as the  $O_2$  pressure within haemoglobin drops, resulting in a poor colour in the finished product. The speed at which the  $O_2$  pressure drops within the sausage mass depends greatly on the viscosity of the skin mass obtained in the first place. Whilst  $O_2$  is easily introduced into a low-viscosity skin mass during cutting in the bowl cutter by the addition of elevated levels of hot water or broth, creating high levels of oxyhaemoglobin, or during mixing of the sausage mass without the impact of vacuum,  $O_2$  pressure drops quickly within a low-viscosity skin–blood or overall sausage mass as  $O_2$  is only loosely trapped. This then supports the formation of methaemoglobin during delays between the production of the sausage mass and thermal treatment. On the other hand, less  $O_2$  is introduced into a high-viscosity skin–blood mass during cutting in the bowl cutter. Smaller amounts of hot water or broth are added during cutting or during mixing of this type of sausage mass but the  $O_2$  introduced remains for a longer period of time in the highly viscous skin–blood mass as elevated levels of viscosity slow down the drop in  $O_2$  pressure within the skin–blood mass.

The amount of blood introduced into the sausage mass also has an impact on the colour in the finished product as less added blood results proportionally in a larger amount of nitrosohaemoglobin. Therefore, less methaemoglobin is obtained given that more NO binds to haemoglobin with the prerequisite that the pH value of blood is below 6.0 and some NO is obtained from undisassociated nitrous acid. As stated earlier, the reason for adding additives such as citric acid is to lower the pH value to around 6.0. If no reduction in pH value in blood occurs, then the colour of the finished product depends even more on the ratio of oxyhaemoglobin to methaemoglobin. A dark and unattractive colour can be the result of many factors: the fact that the

pH value is not reduced to around 6.0 within blood, the long resting times between filling and cooking of the product, thus causing a reduction in the O<sub>2</sub> pressure within the uncooked sausage mass, simply adding too much blood to the product, the fact that the maximum permitted level of nitrite is not being utilized, and the utilization of beef blood instead of pork blood or blood introduced into the hot skin mass during cutting at temperatures above 60 °C, resulting in denaturation of haemoglobin. If the latter is the case, O<sub>2</sub> cannot bind to denatured haemoglobin and is therefore not available for the formation of oxyhaemoglobin any longer. The introduction of other types of gas such as carbon dioxide (CO<sub>2</sub>) or nitrogen (N<sub>2</sub>) during cutting of the skin–blood mass does not support formation of a pleasant colour in the finished product. This is simply because no O<sub>2</sub> is introduced when these gases are added. These cryogenic gases also reduce the temperature of the skin or sausage mass significantly, thus causing an increase in viscosity of the sausage which makes it harder to fill the sausage mass into the respective casings.

Once mixing of the sausage mass is completed, a warm and medium–low-viscosity sausage mass is obtained which is filled easily into the desired casings. Filling of the warm sausage mass commonly takes place by hand, utilizing small buckets or with the help of a filling machine. If a filling machine is utilized, a vacuum must not be applied during the filling process because the application of a vacuum, as described above, removes O<sub>2</sub> from the sausage mass, resulting in a decreased level of oxyhaemoglobin which leads to poor and perhaps grey colour in the finished product. Filling should always take place in a way that no air pockets are present within the filled product as discolouration is seen quickly in those areas owing to the formation of methaemoglobin. Occasional massaging of the filled casing prior to closing of hand-filled products helps to remove possible air pockets entrapped within the sausage mass.

Once filled, the product has to undergo thermal treatment right away to avoid bacterial growth as well as a drop in O<sub>2</sub> pressure. Generally, filled products are cooked with steam or in a hot-water bath at around 85 °C until a core temperature of 72–74 °C is obtained with a temperature of 74 °C frequently aimed for. A reason for obtaining core temperatures of around 74 °C is to ensure the destruction of pathogens as well as all other bacteria since blood has a high bacteria count. These elevated core temperatures (compared with around 70 °C in a cooked sausage such as a frankfurter) are not a disadvantage as separation of fat and water (as in an emulsified product) under the impact of heat is not an issue in non-emulsified products. The products are most often filled into a waterproof casing and thus do not experience any cooking loss (loss in weight) during thermal treatment despite reaching elevated core temperatures. A core temperature of 72 °C fully denatures haemoglobin which subsequently does not penetrate into fat cubes during storage of the product, thus maintaining white-coloured fat cubes. Thermal treatment at such elevated temperatures does not harm the product because

all meat protein present within materials such as precooked shank as well as cooked ham is already completely denatured and not functional any longer.

Another reason for applying elevated cooking temperatures around 85 °C is to shorten the period of time within the cooking process where bacteria could grow as they find perfect living conditions within the warm meat mass. Therefore, a core temperature above 55 °C has to be obtained quickly as bacterial growth is greatly slowed down at those temperatures and bacteria start to be killed at temperatures around 58–60 °C. Long periods of delay between obtaining the sausage mass and reaching core temperatures around or above 60 °C during cooking also favours discolouration of the white-coloured fat cubes as non-coagulated blood penetrates into the outer layers of fat cubes. Applying elevated cooking temperatures raises the core temperature of the product to be cooked above 60 °C within a shorter period of time, thus reducing the risk that blood penetrates into fat cubes.

Once the desired core temperature is obtained, the thermally treated product is cooled quickly to reduce the internal temperature below 10 °C as surviving spores could germinate above 10 °C. A further reduction in core temperature below 4 °C completes the cooling process. Hot products must not be placed in the freezer for cooling purposes as the setting, or formation, of a strong and orderly three-dimensional gel structure (which is obtained during thermal treatment of the product from gelatin originating from collagen present within skin) would be disrupted.

The degree of firmness of sliceable blood sausage is not based on the amount of blood present within the product as coagulated blood is soft in texture. To a large degree, the degree of firmness of the finished product is the direct result of the amount of gelatin obtained which relates to the amount of cooked skin present within the recipe seen in conjunction with the amount of hot water, or broth, added during cutting of the hot cooked skin. To be more specific, large amounts of skin present with little water or broth added to the skin mass during cutting results in a very firm and generally undesirable gummy texture whilst small amounts of skin mass introduced and with elevated levels of water added during cutting of the hot skin-mass results in a soft-textured product. The chilled finished product is consumed in a cold state with bread.

## **29.4 Manufacturing technology for non-sliceable blood sausage**

Non-sliceable blood sausages such as black pudding in the UK or blutwurst (blood sausage) in Germany and Austria are produced from a mix of cured fatty meat trimmings (jowls), PHM and cooked pork skin. In addition, materials such as rusk, cooked barley and cooked rice are applied besides blood. The amount of blood within the product, preferably pork blood, varies between

10% and 60% as a dark-coloured product is required. Generally, fatty cured cooked trimmings, or PHM, are placed in hot water for a while to reheat the materials before being minced with the 6–13 mm blade. Another option is to process cooked materials once they are still hot having been treated with steam or just been removed from the bath of hot water utilized for cooking the meat and fat materials. Hot cooked materials such as barley and rice as well as fried onions are added to the warm minced meat and fat materials and all the ingredients are mixed well. In addition, cooked and hot pork skin is minced with the 3–4 mm blade and added to the mix or is cut in the bowl cutter at a high knife speed while hot broth is added to obtain a finely cut skin mass with a low viscosity, which is introduced into the minced meat and fat materials. Skin applied to the product enhances firmness and also supports the integrity of the cooked product during frying.

Once skin is introduced into the sausage mass, the sausage mass is mixed well and blood, which has been warmed up by placing the container holding the blood into warm water or water at room temperature, is added to the mass at the desired level (15–60%). The addition of blood at levels between 30% and 60% results in a very-low-viscosity mass. During mixing, spices such as pepper, onion, nutmeg, thyme, pimento as well as salt are added and some hot broth for enhanced juiciness of the final product.

In the production of non-sliceable blood sausage the application of the level of nitrite compared with the amount of blood is a matter of choice and decisions are based on the desired colour of the finished product. Although the colour in the sausage is mainly dependent on the amount of blood added, the amounts of oxyhaemoglobin and nitrosohaemoglobin present in relation to methaemoglobin are also significant and nitrite can help to form a good red colour. To produce products with a pleasant red colour, mixtures containing 10–15% added blood often have nitrite added to them as the nitrite added creates a significant amount of nitrosohaemoglobin in relation to oxyhaemoglobin and methaemoglobin and this creates the pleasant red colour in the finished product. The introduction of high levels of O<sub>2</sub> during mixing is also advantageous in order to create high levels of oxyhaemoglobin. If a dark-coloured (almost blackish) product is desired, however, the level of added blood is between 30% and 60%. The amount of nitrite introduced without exceeding the legal maximum limit would be insufficient to turn significant levels of haemoglobin into nitrosohaemoglobin owing to the high level of blood added. As a result, besides processing cured meat and fat materials, all salt added for the amount of blood, skin, cooked rice and other materials is commonly just ordinary salt (NaCl). Even though it does not have a significant effect on the levels of nitrosohaemoglobin, nitrite is nevertheless still frequently added when manufacturing dark-coloured products. This follows the argument that cured nitrite-containing meat and fat materials are already present in the product and further nitrite added to cover the amount of blood and other materials present within the total mass will not be any disadvantage to the product, even though it will not 'improve' the redness

of the product. Contrary to sliceable blood sausage, obtaining high levels of oxyhaemoglobin is not the main aim within a dark-coloured non-sliceable product where the final colour is, first and foremost, based on introducing high levels of blood into the product and, secondly, on the presence of methaemoglobin.

The warm and well-mixed mass is filled immediately into primarily natural casings such as hog or beef casings exhibiting a diameter between 28 and 40 mm. Long delays between obtaining the sausage mass and thermal treatment should be avoided so as not to give bacteria the chance to grow because blood, which is highly perishable, is present within the sausage mass at high levels. Onions are very frequently part of the product and the use of onions can lead to souring of the sausage mass even prior to cooking owing to the large amount of pyruvic acid in the onion when there are long delays between manufacturing the sausage mass and thermal treatment.

The filled and portioned products are subsequently thermally treated with steam or in a hot-water bath at around 85 °C until a temperature of 72–74 °C is obtained in the core. Upon reaching the desired core temperature, the products are showered with cold water for a while before being placed in the chiller. Some products are lightly smoked at temperatures between 20 and 30 °C and smoking should take place during the cooling period once the core temperature of the sausage is around 30 °C. Cooling the product to temperatures below 4 °C and applying smoking afterwards does not make sense economically as the placement of a fully chilled and cold (4 °C or less) product at smoking temperatures (around 25 °C) results in the formation of condensation water. As a result, the cold product has to be ‘warmed’ (dried) first at temperatures between 40 and 50 °C for 10–20 min before smoking can take place, which is an additional cost in the product’s manufacture. The chilled product is commonly vacuum packed and stored at temperatures between 0 and +2 °C; it is finally consumed in a hot state primarily by being fried in a pan.

## **29.5 Summary of critical production issues in the production of sliceable blood sausage**

- 1 Pork skin to be processed must have a low bacteria count ( $10^2$ – $10^4$ ) per kilogram of product, and fresh chilled skin, rather than frozen skin, is preferable.
- 2 Materials utilized as show-meat such as tongues, fatty trimmings or PHM should be properly cured and fully precooked before being cut into cubes of desired size or minced with the desired blade.
- 3 Cut or minced materials should be washed with hot water and allowed to drain.
- 4 Small cubes of pork back fat (if utilized) should be blanched in hot water (90–95 °C) to melt the fat in opened fat cells to avoid penetration of blood into the fat cells.

- 5 All washed, drained, warm materials should be mixed with hot, finely cut skin mass while the mixture is stirred and warmed blood (at least room temperature) is added.
- 6 Alternatively, blood can be introduced into the hot skin mass directly but the temperature has to be below 60 °C as haemoglobin would denature otherwise.
- 7 No vacuum is applied during mixing whilst all spices, salt and nitrite are added as the removal of O<sub>2</sub> favours formation of unwanted methaemoglobin.
- 8 The final colour in the product depends largely on the amount of oxyhaemoglobin and nitrosohaemoglobin present in relation to methaemoglobin
- 9 Filling takes place immediately to avoid long delays between obtaining the sausage mass and thermal treatment (risk of bacterial growth, souring of the product and the reduction in O<sub>2</sub> pressure favouring formation of methaemoglobin). Filling takes place without the application of a vacuum.
- 10 Thermal treatment of filled product should be carried out at around 80–85 °C until a core temperature of 72–74 °C is obtained.
- 11 A core temperature of 72 °C is required to denature haemoglobin fully and to avoid reddening of white fat cubes as insufficiently denatured haemoglobin penetrates into fat cubes during storage.
- 12 The thermally treated product should be cooked below 10 °C quickly to avoid germination of spores and the further speedy cooling to below 4 °C is carried out.
- 13 The chilled product should be stored at temperatures between 0 and 4 °C.

## 30

# Typical blood sausage products from around the world

### 30.1 Thüringian blood sausage (Germany)

Countless different products containing blood are produced in Germany. There is no standard recipe for Thüringian blood sausage as various products with this name are produced in several regions of Germany in different ways. However, there are some common factors among the different types of Thüringian blood sausage. These products are generally sliceable and most commonly contain PHM, fatty pork trimming, jowls (skin and glands removed) or cubed ham as visible meat particles or show-meat, which makes up 60–70% of the finished product. To produce the sausage, these ingredients are treated with salt and nitrite and are then cooked to obtain cured meat materials.

The ham or PHM is usually cut into cubes of 1 cm × 1 cm × 1 cm and fatty trimmings are occasionally minced with the 8–13 mm blade. All the show-meat is then washed with hot water and allowed to drain. Cooked pork skin is then cut in the bowl cutter at a high knife speed while hot water or hot broth is added until a hot low-viscosity skin mass is obtained. The hot skin mass is added to the warm, cut or minced and drained pieces of show-meat at a level of around 25–35% and all the ingredients are mixed well while spices such as pepper, cloves, pimento, marjoram and onion are added. Warmed and stirred blood (most commonly pork blood) is subsequently added to the mixed mass at a level of around 6–8%, which results in a lovely red colour in the finished product. During final mixing, the level of salt is adjusted so that it is 1.8–2.0% in the final product, as the added blood and hot skin mass did not contain any salt or nitrite. The mixed warm mass is filled immediately into large-diameter (greater than 100 mm) waterproof casings, which are

then thermally treated with steam or in a hot-water bath at 85 °C until a temperature of 74 °C is reached in the core. Upon obtaining the desired core temperature the product is cooled quickly and stored at 0–4 °C and is consumed in a cold state.

### **30.2 Blood–tongue sausage (Austria)**

Blood–tongue sausage contains around 45–50% precured, cooked and cubed pork tongue. The tongues are commonly cut into only two or three pieces so that the finished product contains large pieces of tongue. The cut pieces of tongue are then washed with hot water and allowed to drain. Pork back fat is cut into small cubes of around 5 mm × 5 mm × 5 mm before being blanched in hot water and allowed to drain. The back fat is then added to the drained and warm pieces of pork tongue. The fat cubes make up around 20% of the finished product. Hot broth is added to skin while it is cut in the bowl cutter, until finely cut hot skin mass is produced. This accounts for around 30% of the total mass of the final product. During the mixing of all the warm materials, spices very similar to those used in the manufacture of Thuringian blood sausage are added, usually before the hot skin mass is introduced. All the ingredients are gently mixed and 5–8% warmed stirred pork blood is introduced into the mass. Mixing is continued, and salt and nitrite are introduced at an appropriate level as the fat cubes, pork skin and blood were not salted prior to use. The level of salt in the final product is 1.8–2.0%. The warm well-mixed mass is filled without delay into large-diameter waterproof casings or occasionally into natural casings such as pork stomachs. Thermal moist heat treatment subsequently takes place, either by the application of steam or in a bath of hot water at around 85 °C until a core temperature of 74 °C is reached. The product is cooled to below 4 °C and stored at this temperature before being consumed cold, most commonly with bread.

### **30.3 Black pudding (England)**

Black pudding in the UK commonly does not contain any muscle tissue. A basic recipe would contain around 50% blood, 30% cubed pork fat, 15% cooked barley and 5–8% rusk. Depending on the region in which it is produced, black pudding sometimes does not contain any large visible pieces of fat and is instead just made from blood (around 60%), barley, rusk, spices and salt as well as lard (around 20%). This type of sausage is produced by mixing warmed blood with barley and rusk to obtain a lump-free mix before the warmed lard is introduced. During mixing, spices such as black and white pepper, pimento and clove as well as salt are introduced. The level of salt in the final mixture is around 1.6–1.8%. Commonly, beef blood is utilized to

obtain the desired black colour but, owing to the recent bovine spongiform encephalopathy (BSE) crisis, pork blood is nowadays processed as well. Occasionally, colours such as azo dyes are added to the sausage mass in order to ensure a black colour in the finished product. The mixed sausage mass is subsequently filled into natural hog or beef casings between 28 and 34 mm in diameter and is then thermally treated with steam or in a bath of hot water at 85 °C until a temperature of 76–78 °C is reached in the core. This temperature ensures complete coagulation of blood which holds the product together. Black pudding is generally fried in a pan and consumed hot.

### **30.4 Black pudding (Austria)**

Black pudding in Austria is similar to black pudding in the UK but meat materials such as cooked PHM, cured and cooked jowls as well as cooked pork skin are introduced. A typical recipe would contain around 45–50% cured and cooked PHM, 10–15% cooked pork skin, 20–30% pork blood as well as 10–15% cooked rice, barley and some fried onions. Black pudding in Austria is not as dark in colour as black pudding in the UK because the quantity of blood introduced is significantly smaller and hot broth is also added at around 5–7% for enhanced juiciness. To produce black pudding, cooked boneless PHM can be warmed in hot water and then minced with the 8–13 mm blade. Alternatively, bone-in pork heads are placed in steam or a bath containing hot water, removed once fully cooked and deboned to obtain warm boneless meat and fat material. Cooked cured jowls are frequently processed as well, but PHM is the first material of choice. In the meantime, freshly cut onion is fried in a pan; barley and rice are added and these ingredients are covered with water and cooked for around 30 min. Fully cooked rice and barley are added to warm minced PHM. Hot pork skin, which has been minced with a small blade such as a 2–3 mm blade, is introduced as well and, during mixing of these warm materials, blood and broth are added. The addition of spices as well as salt (and nitrite) completes the process. The spices utilized are marjoram, caraway, clove, pimento, pepper and a touch of garlic, with salt being present in the final product at 1.9–2.0%. The warm and mixed sausage mass is filled into hog or beef casings of 28–34 mm diameter and the product is thermally treated with steam or in a bath of hot water at 80–85 °C until a temperature of 74 °C is reached in the core. The cooked product is subsequently showered and cooled to a temperature below 4 °C. In some regions of Austria, the cooked product experiences a slight degree of smoking during cooling. The finished product is fried and eaten hot as a main meal predominantly with bread and sauerkraut (fermented raw cabbage).

## 31

### Brawn and meat jellies

The terms 'brawn' and 'meat jelly' are often used interchangeably, but in fact they are two different products. Brawn is a good way of using the low-value parts of a pig, such as the head, skin, shank (hocks), tongue and heart, to obtain flavoursome and nutritious meat products. The production of brawn in small factories and restaurants uses traditional methods. The raw materials are typically the collagen-rich parts of the pig, such as the head, shank and skin. These are cooked for a long time and the naturally occurring gelatin produced during the cooking process holds the mass together when it is cold. Brawn produced in this way does not need added gelatin and traditionally does not contain added nitrite. Large-scale production of brawn uses the same raw materials but they are cured (with added nitrite), precooked and handled separately, with gelatin solution being added later in the production process. Another difference between the two methods is that traditional brawn is not usually reheated once it is set, whereas brawn produced on a large scale is commonly cooked for a second time after the mixed mass has been filled into waterproof casings.

Meat jellies are sometimes referred to as brawn but are not based on the same raw materials. Meat jellies are mostly made using lean cured or uncured pieces of meat, such as chicken breast (mostly uncured) or cooked ham made from pork or beef. The meat is usually cut into cubes of various sizes and mixed with a gelatin solution before being filled into waterproof casings or moulds. Meat jellies do not normally contain any visible fat or minced pork skin and are typically sold as a high-quality product because they are very low in fat (less than 2%). Both brawn and meat jelly are eaten cold.

### 31.1 Selection and preparation of raw materials

Meat jellies contain show-meat, which are precooked lean pieces of cured or uncured cooked meat. One common show-meat is injected whole-muscle cooked ham (see Chapter 8), typically produced from pork shoulder or leg meat and extended by 20–40%; another is cooked shank meat. Other types of ham may also be used as show-meat. The show-meat is commonly cut into cubes, with sides ranging from 5 to 25 mm in length. Cooked shank meat, usually without any skin or fat, is either cubed or minced with a large mincer blade (13–20 mm). Large blades are used because large pieces of lean meat in the end product are more attractive to the consumer, suggesting a higher-quality product. There are some farm-style meat jellies made with shank meat where the fat and skin are not totally removed, and these can still be seen on the show-meat.

The first step in making meat jelly is either to soak boneless shank meat (with or without skin) in brine containing around 10–15% salt and 1500–2000 ppm (0.15–0.2%) of nitrite per litre of brine, or to inject the brine, usually into bone-in pork hocks. Injection speeds up the introduction of salt into the muscle tissue and also the development of curing colour. The injected meat is then soaked in brine, containing 300–400 ppm of nitrite per litre as well as 3–4% salt, for an additional 1–2 days. Occasionally, pork hocks are just soaked in brine under chilled conditions to cure them, but this takes much longer, 7–10 days. Once cured, the meat is heated with steam or in a hot-water bath at around 90 °C until a core temperature of 70 °C is reached. Bone-in hocks are thermally treated until the bones can be removed easily while the meat is still warm. Care must be taken to ensure that bone-in hocks are properly cured. Any non-cured areas would appear grey in the finished product, despite the later addition of nitrite into the gelatin solution.

Chicken breast meat is frequently used as show-meat because its light colour suggests a healthy product, and because there are no religious or cultural considerations that prevent the consumption of chicken. Again, there are two main methods. The first method consists of injecting the breast meat with 20–40% brine, containing phosphates and salt, and tumbling it under vacuum until all the brine is fully absorbed and the meat shows a degree of tackiness. An alternative method is simply to tumble the breast meat by adding 15–25% brine to the meat without being injected. The level of extension in the second method is less, because less brine is absorbed by muscle tissue during tumbling than through injection. After tumbling the chicken is filled into casings and cooked in steam or in a hot-water bath at 76–80 °C until a core-temperature of 70–72 °C is obtained, creating a kind of brine-added chicken ham (see Chapter 10). Tumbled meat is also cooked with steam by being placed on racks at similar temperatures without being filled into a casing. This results in a higher cooking loss than if cooked inside a casing.

Lean beef muscle tissue used as show-meat is commonly treated in a very similar way to chicken, being injected with 20–40% brine, containing

phosphates, salt and nitrite, before being tumbled under vacuum and cooked in casings with steam or in a hot-water bath until a core temperature of 70–72 °C is reached. Another method of obtaining show-meat based on beef, which is very similar to chicken, is to produce a kind of brine-added ham. This is filled into waterproof casings, has an extension of up to 40% and, besides phosphates and salt, contains additives such as carrageenan and starch so that there is no cooking loss. The amount of salt in the cooked material is around 1.5–2.0%.

A selection of PSE pork and DFD beef used as raw materials for cooked and cured show-meat is not of great importance as the functionality of the muscular proteins and the WHC of these meats is not vital for the finished product. Fully cooked meat or ham is used within the finished product only as show-meat and the added gelatin solution is solely responsible for sliceability of the product.

Whereas most meat jellies do not contain any skin or fat, brawn contains shank meat and PHM with fat and skin, and precooked pork skin is frequently added as well. PHM is obtained by cutting pig heads in half and curing them for a few days in brine containing around 10–14% salt and 1500–2000 ppm of nitrite per litre, or injecting them with a similar nitrite-containing salt solution (see Chapter 25, Section 25.3). The cured heads are thermally treated with steam or in a hot-water bath at around 90 °C until the bones can be easily removed by hand, and the boneless meat and fat material can then be used to make brawn. Pork hocks are also often used for brawn, generally being injected before being soaked in brine for a short time and then cooked. The bones are removed while the cooked hock is still warm, because it is easier than when the bone-in hock is cold. If used, 75–80% CL-grade pork trimmings are soaked in brine for several days under chilled conditions until fully cured and then cooked until a core temperature of around 72–74 °C is reached.

After cooking, the meat materials are rarely processed immediately. Instead they are stored either in trays or in an ice–water slurry containing around 2% salt. In both cases, the cooked meat materials must be cooled quickly to avoid bacterial growth. They are then stored at 0–4 °C for up to a maximum of 48 h before being processed further. Chilled materials are easier to cut or mince than warm materials, and cooked shank meat as well as PHM can be stored frozen and are then thawed in warm water before processing. Brawns often contain tongues and hearts. Pork tongues and hearts are soaked in brine containing 10–14% salt and 1500–2000 ppm of nitrite per litre. Beef tongues are injected with 10–15% brine before being soaked in brine for another 2–3 days before being cooked. Once cured, tongue and heart meat is cooked in steam or a hot-water bath at around 80–85 °C until fully cooked. The outer layer of the tongue must be removed as otherwise this layer gives the finished product a bitter taste (see Chapter 29, Section 29.1). Hearts must be cut open before curing in order to remove any blood clots. Cooked heart meat is commonly minced (4–8 mm blade) or cut into small cubes (5 mm × 5 mm ×

5 mm) because it is very dark in colour and larger pieces would stand out too much in the finished product. The proportion of heart meat used to make brawn is generally not more than 5–10% of the total meat and skin material. This results in around 3–7% in the finished product as all meat materials account for around 65–70% of the total mass and the gelatin solution accounts for the remaining 30–35% of the finished product. The functionality of heart and tongue meat with regard to ability to immobilize water and to emulsify fat is not important in brawn production because the proteins are completely denatured before further processing. Heart and tongue are not of fibrillar structure like actin and myosin and therefore show a very limited WHC by nature.

All meat materials for brawn production should have a low bacteria count, with no signs of sliminess, discolouration or unpleasant smell.

### **31.1.1 Treatment and use of pork skin**

Collagen turns to gelatin during heat treatment, and materials such as PHM, shanks and pork skin generate sufficient gelatin to bind brawn naturally, without the need to add extra gelatin, which is utilized when producing home-made or old-style brawn.

Pork skin is a highly valuable material, rich in connective tissue and collagen, and is commonly used in brawn but not in meat jelly. Pork skin used for large-scale brawn production must have a low bacteria count and all hairs and fat should be removed. The pork skin should not have an unpleasant smell or any signs of being slimy. Any areas with veterinary stamps (usually coloured inks) or blood marks should be cut out, so that they do not discolour the finished product. Pork skin is thermally treated in steam or a hot-water bath at around 90–95 °C until softened, i.e. until the skin still demonstrates some degree of firmness but is not hard any more. Occasionally, pork rind is placed in brine containing nitrite for 12–24 h, but from a technological standpoint this does not make much sense as there is no myoglobin present in skin to develop a curing colour by the impact of nitrite in conjunction with myoglobin. The benefit of placing the skin in brine, however, is that it can be stored under chilled conditions for longer than without brine.

## **31.2 Selection of additives**

Parameters such as WBC and cooking yield are not of great importance in brawn and meat jelly, so additives such as phosphates, proteins (except gelatin), carrageenan and starch are not used. The only exception is when cooked ham is used as show-meat for meat jelly, because cooked hams typically contain additives such as phosphates, carrageenan and salt within the manufacturing process of the ham itself.

The primary purpose of the salt in the curing brine is to enhance the flavour within the meat. Salt also causes protein swelling in materials such as shank meat, thus increasing the WHC of cured meat during cooking. Salt added into the gelatin solution has no impact on the functionality of proteins because the materials (show-meat) are fully cooked before further processing. The amount of salt in the final product varies greatly and is usually between 10 and 20 g per kilogram of product. It is easy to produce low-salt brawn and meat jellies because the binding is due to the gelatin and not to activated protein (as within cooked ham or cooked sausage), where the addition of salt is required in order to activate significant amounts of native protein.

Nitrite is used for its contribution to flavour and colour in cured cooked materials such as PHM, hocks and tongues. The amount of nitrite in the final product must conform to the maximum permitted legal limits. Colour enhancers, such as ascorbate or erythorbate, are occasionally added during curing, at around 0.2–0.3% within the curing brine. An injection brine, introduced at around 10–15% into pork heads or hocks, typically contains around 10–15% salt, around 0.2% nitrite and around 0.3% erythorbate.

Vinegar is frequently added to brawn and meat jelly to lower the pH, giving the product a slightly sour taste. The amount of vinegar added depends on the strength of the vinegar itself and a pH in the finished product of around 4.5–5 is generally preferred. Spices and herbs are added according to taste, and other flavours, such as red or white wine, or onions (roasted, powdered, etc), are used to produce a distinctive and value-added product. Vegetables such as peas, carrots and corn can be used and are usually cooked before being added to the brawn or jelly. Pickled cucumbers should be washed first with water to remove surface acidity and drained before being added to brawn or meat jelly, because they can otherwise denature the surrounding gelatin, which would cause the pieces of cucumber to fall out of the slices.

Gelatin used in the production of brawn and meat jelly is made from around 85% protein, 10–12% water and 3% minerals. Gelatin (see Chapter 6, Section 6.1.8) of different bloom values can be used. The chilled and solidified gelatin solution is ultimately responsible for the sliceability of the finished product and the type of gelatin added (high or medium bloom), and the concentration of gelatin in the solution greatly determines the final gel strength. Most types of gelatin should be soaked first in lukewarm water for around 15 min to swell before being added to hot water. From a nutritional point of view, gelatin contains most essential amino acids.

### **31.3 Manufacturing technology for brawn**

The traditional method of making brawn is only used for small-scale production, for instance in a restaurant where it will be served soon after making. The traditional method involves thermally treating collagen-rich materials, such

as pork head, hocks and shank meat, for several hours at 90–95 °C. Vegetables are often added, and common table salt is used.

The resulting cooked meat materials are grey in colour (non-cured). They are deboned, and the meat, fat and skin obtained are commonly minced, or simply chopped, into smaller pieces and mixed into a hot cooking broth. Spices, such as pepper, cardamom, garlic and ginger, salt and vinegar, are added according to taste and the finished mass is filled into moulds, or trays, and chilled. The gelatin present in the broth acts as the binding glue, and a sliceable product is obtained upon cooling. The grey colour does not bother the consumer as it symbolizes the home-made nature of the product.

Brawn produced on a larger scale contains precured and fully cooked materials such as PHM or shanks, or a mix of both, and may contain cured and cooked tongues and hearts as well. The meat and fat material is commonly diced into 0.5 cm × 0.5 cm × 0.5 cm to 3 cm × 3 cm × 3 cm cubes, following the general rule that lean materials are diced into larger cubes and fatty material into smaller cubes because consumers do not like to see large pieces of fat in the finished product. When brawn is made from lean shank meat alone, the meat is minced with a kidney blade so that large and non-uniform pieces of meat are obtained. This gives a traditional appearance to the final product.

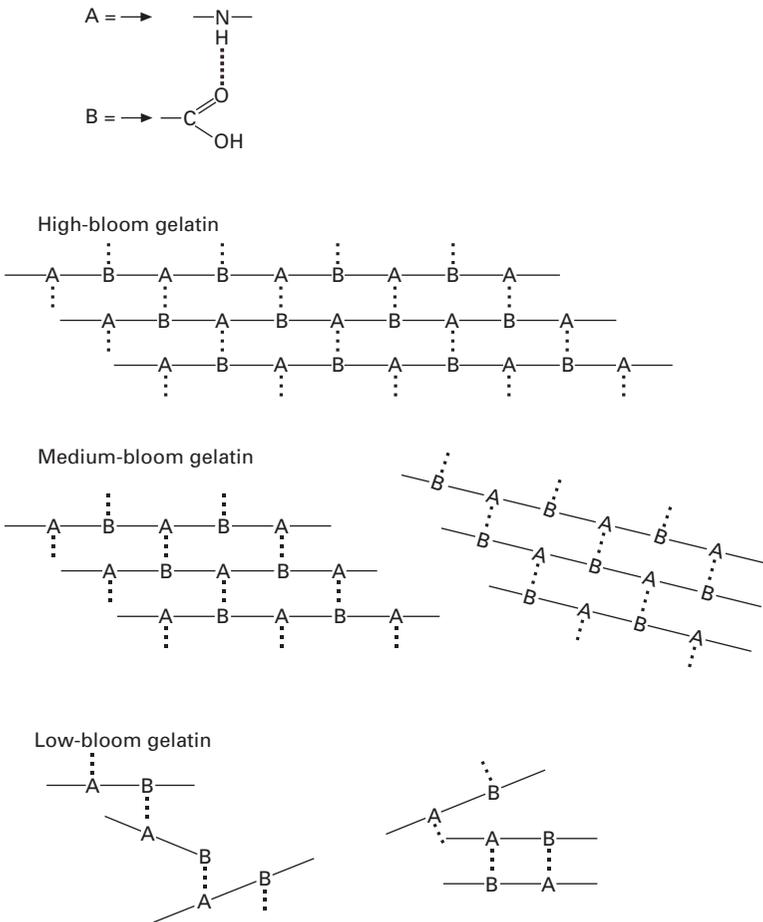
The diced, cut or minced material is then washed with hot water to remove all possible traces of fat and protein from the surface and then allowed to drain. This prevents cloudiness in the final gel. If cooked pork skin is used, it is minced, normally when hot, with the 4–6 mm blade and then washed with hot water and allowed to drain. The decision of whether to add pork skin, and the amount added, depends on the quality of the product being made and generally varies between 5% and 15%. Some types of brawn are made in such a way that large pieces of cooked pork skin are visible, to imitate a home-made product.

The washed and drained materials are mixed, while still warm, with any other precooked materials specified in the recipe, such as cubed carrots or pickled cucumber.

The gelatin solution is prepared by first mixing the gelatin with tap water and allowing it to swell for around 15 min. This mixture is then gradually added to hot water at around 80 °C. Gelatin must not be added to boiling water because this reduces final gel strength dramatically. The mixture is stirred continuously until the swollen gelatin has dissolved. Any other additives, such as extra salt, vinegar and flavourings, are added to the gelatin solution and mixed until the solution is clear, at which point all the gelatin is fully dissolved. The amount of salt added to the gelatin solution depends on the desired level of saltiness in the final product, bearing in mind that all precooked and precured materials already contain salt. The finished product usually contains around 2–2.2% salt. Vinegar is added to lower the pH and should be added after salt during the preparation of the gelatin solution. If vinegar is added before the salt, it is much harder to achieve the correct level of salt in

the finished product as the vinegar taste masks the saltiness. Vinegar can also denature collagen, so it is normally added to the gelatin solution as late as possible before filling and thermal treatment of the product. If wine is used, it should be added as late as possible to the gelatin solution for the same reason. A pH between 4.6 and 5.0 is preferred in the finished product. Sugar can be added to the gelatin solution to cover up the taste of vinegar if it is not desired. Vinegar improves shelf life because a pH of 4.5–5.0 prevents bacterial growth.

Gelatin is available with different bloom values. High- and medium-bloom gelatins form a more solid gel than low-bloom gelatins but are more expensive. High-bloom gelatin has a bloom value of 220–280, with medium-bloom values being between 100 and 200. Low-bloom gelatin (40–100) is not generally used in brawn or meat jelly because the resulting gel is too soft. Figure 31.1 shows the different types of gelatin and their ability to form a gel.



**Fig. 31.1** Different types of gelatin and their gel-forming properties.

The bloom value is a test of the force required to press a stamp or cylinder of specified size and diameter 4 mm deep into a gel that contains 7% gelatin and has been stored at 10 °C for 18 h before being tested. Around 20% more medium-bloom gelatin must be used to achieve a gel strength comparable with high-bloom gelatin. Solid gels are obtained by introducing 10–15% of high-bloom gelatin into the solution, and higher gel strength can be obtained by simply adding more gelatin to the solution. More gelatin should be added to compensate for a high level of vinegar or wine, which would otherwise reduce gel strength. The desired gel strength and therefore, to a large degree, firmness of the finished product depend on the bloom value of the gelatin used in the solution, the amount of gelatin added to the solution and the amount of gelatin solution in the finished product. If cooked pork skin is used, less gelatin is needed to obtain the desired gel strength, because gelatin from the pork skin contributes to firmness.

The firmness of the gel is affected by pH and drops by around 15% if the pH is lowered from 5.0 to 4.0. More gelatin must be added to compensate and achieve a comparable firmness.

There are two methods of combining the washed and drained meat materials with the gelatin solution. The most common method is to mix the gelatin solution gently with the washed and drained meat material, with the amount of gelatin solution usually being around 30–35% of the finished product. Excess mixing should be avoided as it destroys the structure. Salt and/or nitrite are added if necessary, and then the mixed mass is filled into waterproof casings.

An alternative method is to put the meat materials into the waterproof casing first, and then to add warm–hot gelatin solution to each individual casing. Again the amount of gelatin solution is around 30–35% of the final product. This method can be refined further, resulting in a highly standardized and consistent final product because the amount of meat in each casing is predetermined and a standardized amount of gelatin solution is added to the meat. In both methods, the casing is finally tied or clipped after removing all the air. Traditional products occasionally use waterproof casings in the shape of a pork stomach, and very rarely natural casings such as pork stomachs are used. The filled product is usually pasteurized in steam or a hot-water bath at around 78–82 °C until a core temperature of around 72 °C is reached. The gel strength in the finished product is considerably reduced if temperatures above 85 °C are applied for a long period of time, and a stronger gelatin solution must be used to compensate for this higher temperature treatment if used.

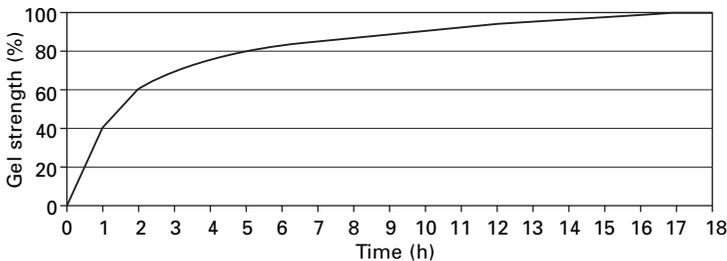
Cooling after thermal treatment must be controlled so that the gel sets properly. The hot pasteurized product must not be placed directly in the blast chiller or freezer immediately because, if chilling occurs too quickly, the viscosity within the product increases rapidly and the three-dimensional gel will not set correctly. This results in lower gel strength, poor sliceability and even formation of purge in severe cases. After pasteurization, the hot product

should be kept at room temperature for around 1–3 h before being placed in a chiller at 2–4 °C, to give the gel time to set. The product should not be turned, squeezed or twisted during cooling because this will also disturb the formation and setting of the gel. It takes around 16–20 h for the gel to form and set after pasteurization, and the gel strength in the finished product will depend on bloom value of the gelatin used, the concentration of gelatin in the solution, the speed of cooling and the pH of the product itself. It should be noted that using more of a medium-bloom gelatin rather than less of a high-bloom gelatin in order to achieve the desired firmness can result in a tacky and elastic texture. Figure 31.2 shows the increase in gel strength over time during cooling.

The firmness of a gel also depends a great deal on the storage temperature, with warmer temperatures significantly reducing firmness. At temperatures between 2 and 4 °C, there are minor or no significant differences in gel strength between medium- or high-bloom gelatin, but significant differences are seen at temperatures around 10–15 °C. The highest gel strength is obtained at a pH around 5.0 and after thermal treatment between 78 and 82 °C to a core temperature of 72 °C. The gel strength is influenced more severely by high cooking temperatures of the product than by a reduction in pH. A lower pH reduces gel strength because the acid, acetic or tartaric, found in vinegar or wine adds H<sup>+</sup> ions to the gelatin solution. These H<sup>+</sup> ions interfere with the formation of the gel, and the degree of interference depends on the amount of acid present.

If very hard water is used to make the gelatin solution, the resulting gel can be murky. This is because the calcium salts in the hard water react with salt from the gelatin, leading to the formation of insoluble visible particles.

Brawn that is sold in blocks or sliced into 1–2 cm slices is commonly filled into trays in layers around 5–10 cm thick whilst the mixed mass is still warm. The filled tray is stored in chilled conditions overnight and blocks of 0.5–2 kg, or slices, are cut the next day and subsequently vacuum packed. These products must be handled very hygienically once placed in the trays, as there is no further heat treatment to kill bacteria. Normally, finished brawn that has a pH around 4.6–5.0 is vacuum packed and stored between 0



**Fig. 31.2** The development of the gel strength of an 8% gelatin solution during cooling by 5 °C.

and 4 °C; it has a long shelf life, as the combination of acidity and low storage temperatures inhibits bacteria growth.

### 31.4 Manufacturing technology for meat jellies

Meat jellies are generally made from lean pieces of cured and non-cured meat products, which are cut into cubes of various sizes, from 5 mm × 5 mm up to 3 cm × 3 cm × 3 cm. Hams made from injected whole muscles of pork or beef (see Chapter 8) as well as brine-added hams (see Chapter 10) can be used. The level of extension in such whole-muscle hams is quite low, between 20% and 40%. Chicken breast used for meat jelly is typically 15–30% injected, tumbled and cooked as a whole piece in steam or a hot-water bath at 76–80 °C until a core temperature of 70–72 °C is reached.

The fully cooked and chilled materials are diced, washed with hot water and allowed to drain to remove any remaining traces of protein and fat and so ensure a clear gel in the finished product. The cubed material is sometimes mixed with other materials, such as herbs, cracked pepper or even cubed cheese, before being placed in waterproof casings. The gelatin solution is prepared in the same way as in brawn production, and additives such as red or white wine are frequently added to the gelatin solution to create a higher-value product.

Most meat jellies follow the principle that a certain amount of meat material is placed in the waterproof casing together with a specified amount of gelatin solution. This results in a consistent product that always demonstrates the same ratio of show-meat to gelatin solution. The casings are tied or clipped, ensuring that no air bubbles are left in the filled product, and then thermally treated in steam or a hot-water bath at 78–82 °C until a core temperature of 72 °C is reached. Square-shaped meat jellies filled into waterproof casings are placed in a mould prior to thermal treatment. The thermally treated product is left to stand at room temperature for a while before being placed in the chiller to allow the gel to set properly and then stored at 0–4 °C. Another way to produce meat jellies is to place the cooked, diced, washed and drained pieces of meat in moulds and then to add hot gelatin solution to cover all meat and to set it in the usual way. Such products are not thermally treated any longer. A more complex process involves putting a small amount of gelatin solution in the mould first and allowing it to set in the chiller. Herbs, slices of oranges and apples, and other materials are placed on the layer of set gelatin, and then another thin layer is poured on top. This second layer is also allowed to set, before the meat and the rest of the gelatin are added to fill up the mould. This decorative layer of gelatin including herbs and other materials is called a 'mirror', creating a high-quality image of the product. The gelatin solution frequently contains red or white wine, brandy or other alcohols to create a value-added high-quality product. Once the gel is completely solidified, the meat jelly is vacuum packed. Sometimes the

product is vacuum packed in the mould; otherwise it is removed from the mould by dipping the mould in hot water for a short period of time, which liquefies a small amount of gel at the interface between the jelly and the mould, and then turning the mould upside down to release the jelly. This is then vacuum packed as normal. Finished products are stored at 0–4 °C.

A large percentage of meat jellies are sold as ‘low-calorie’ or ‘low-sodium’ products. Theoretically, meat jellies can be produced without any salt, because binding and sliceability are due to the gelatin and not to activated muscular protein.

### **31.5 Summary of critical production issues in the production of brawn**

- 1 All meat material to be processed must have a low bacteria count and show no signs of discolouration, slime or deterioration of flavour.
- 2 Precured and cooked meat material should contain around 2% salt as well as around 100 ppm of nitrite (legal limits to be observed).
- 3 All meat materials must be fully cooked before being further processed, and bone-in materials should be cooked to the point where the bones can easily be removed.
- 4 Skin should be cooked at 90–95 °C until soft but not overcooked.
- 5 Cubed or minced materials must be thoroughly washed with hot water and allowed to drain to remove all possible traces of protein and fat, to ensure that the gel in the finished product is clear.
- 6 Sour materials, such as pickled cucumber, must be washed with water to reduce acidity.
- 7 The gelatin solution should be prepared according to the type of gelatin used and the supplier or manufacturer’s recommendations.
- 8 Vinegar (or any other sour material) should be added to the gelatin solution after salt so that the exact level of salt in the solution can be determined accurately.
- 9 Products filled into waterproof casings must have all the air removed before the casing is tied or clipped.
- 10 Products should be heated at 78–80 °C until a core temperature of 72–74 °C is reached.
- 11 The hot product must be cooled slowly at room temperature to start with, before being placed in a chiller at 2–4 °C for around 12–18 h, to ensure that the gel sets properly.
- 12 Finished products should be stored at 0–4 °C.

## 32

# Typical brawn and meat jellies from around the world

### 32.1 Presswurst (brawn) (Austria)

Presswurst is a typical Austrian meat dish served cold with onion rings, oil, vinegar and sour dough bread. Presswurst is occasionally still produced by restaurants in the traditional way. This method involves cooking collagen-rich materials for several hours, introducing some spices into the broth obtained during cooking and placing the boneless meat into a mould. The gelatin obtained during the long cooking process from materials such as PHM, shanks and skin makes the total mass solidify once it is chilled. When manufactured on a larger scale, presswurst is produced from precured and precooked pork head, shank meat (deboned pork hocks) and cooked pork skin. Pork hearts and cured and cooked pork tongues are also often frequently used. Several different types of presswurst are available. A typical presswurst contains around 5–10% cooked pork skin minced with the 4–6 mm blade, 50% diced PHM in pieces of around 1.5 cm × 1.5 cm × 1.5 cm and 5% pork hearts. Gelatin solution accounts for the remaining percentage. All the well-cooked and boneless meat, heart and skin materials are washed with hot water and allowed to drain so that a clear gel is obtained in the finished product, which makes all the meat particles clearly visible. Spices frequently introduced are onions, pepper, salt (around 2% in final product) and vinegar. In addition, materials such as cubed cooked carrots are introduced regularly as they add to the visual appearance of the product. Gelatin solution is prepared as per the supplier's recommendation and the correct amount of vinegar is added so that the final product has a pH of around 4.6–5.0, as the consumer likes this slightly sour taste.

Gelatin solution is added to the washed and drained meat materials at a level of around 30–35% and all the ingredients are well mixed. The warm

mass is then filled into large-diameter waterproof casings. The product is pasteurized at around 80–82 °C by the impact of steam or in a bath of hot water until a core temperature of around 72 °C is reached. If steam is applied, the filled product is placed horizontally on to racks; otherwise it is just placed in a bath of hot water. Occasionally, presswurst is filled into pork stomachs and then thermally treated in the same way as products filled into waterproof casings.

### **32.2 Farmer's brawn (Austria and Germany)**

Farmer's brawn is generally produced from large pieces of precooked cured boneless pork shank meat with the skin on. PHM is occasionally used as well. Cooked and chilled shank meat is either diced into large cubes or cut with a kidney blade so that large pieces of meat are obtained. After thorough washing with hot water, the pieces of meat are allowed to drain. They are then mixed with spices large enough to be visible in the final product, such as green peppercorns. The peppercorns are washed with water and drained to reduce acidity before use. Occasionally, additives such as red or white wine are introduced into the gelatin solution to add a more interesting flavour to the product. Vinegar is added to the gelatin solution in the last stages of its preparation. Cooked and minced pork skin is generally not used in high-quality brawn products and its inclusion is not really necessary as shank meat with the skin on is commonly used. The level of gelatin solution introduced is only around 20–25% as a meaty-looking finished product is desired. The pH value of the product is around 4.8–5.0 and around 2% salt is present in the final product. The gelatin solution and the washed and drained meat materials are gently mixed together. The hot mass is frequently filled into waterproof casings resembling natural casings such as pork stomachs, but natural pork stomachs themselves are frequently used as well. Thermal treatment takes place in the same way as described in Section 32.1.

### **32.3 Meat jellies**

The starting ingredients of meat jellies are produced from lean pieces of pork, beef or quite often chicken breast. These raw materials have been converted either by injecting brine into muscle tissue or by adding brine to smaller minced pieces of meat (see Chapters 8 and 10). The level of extension within these products is moderate and commonly between 25% and 35%. Salt and phosphates are the usual ingredients added. Injected pieces of meat are tumbled for a while before being thermally treated. The product can be thermally treated directly, either with steam or by being immersed in a bath of hot water at a temperature of around 76–80 °C until a temperature of 70 °C is reached

in the core, or it is filled into fibrous or waterproof casings before being thermally treated. The fully cooked and chilled product is cut into cubes of various sizes, ranging from very small (0.5 cm × 0.5 cm × 0.5 cm) up to large (3 cm × 3 cm × 3 cm), before being thoroughly washed with hot water and allowed to drain. This enables a clear gel to form in the finished product. The level of gelatin solution in the finished product varies between 25% and 35%. Many different additives such as herbs, cooked vegetables and wine are frequently introduced into the gelatin solution as well. Salt is present in the final product at a level of around 1.6–1.8%. Warm or hot meat jellies are filled into either waterproof casings or moulds. Products filled into moulds are not thermally treated again and are left to set. Products filled into waterproof casings are pasteurized at 78–82 °C until a temperature of 72–74 °C is reached in the core. They are then cooled and stored at 0–4 °C.

### **32.4 Chicken meat jelly (handmade)**

Chicken meat jelly is produced from skinless boneless chicken breast, which has been injected at a level of around 25–30% with brine containing salt and phosphates. After being tumbled, the chicken breast is thermally treated either with steam or in a bath of water at around 76–80 °C until it is fully cooked through. It is subsequently cooled. Around 1.6% salt is present in the cooked meat material whilst the level of phosphates is around 0.3–0.4%. The hot gelatin solution commonly contains herbs and white wine as well as a touch of vinegar. A small amount of the gelatin solution is poured into a mould and the mould is then placed in the chiller for a short while. Once the solution has solidified, thin slices of oranges (or other fruit such as apples) are placed on top of the layer of solid gelatin. A small amount of hot gelatin solution is added once again to fix the slices of fruit in place and the moulds are placed in the chiller again. Upon solidification, whole pieces of cooked and chilled chicken breast are placed neatly into the mould before the entire mould is filled with hot gelatin solution. The full mould is placed in the chiller overnight for the product to solidify. The solid product is sold either in or out of the mould. If sold in the mould, the mould is vacuum packed. If the product is sold out of the mould, the mould is dipped into hot water for a short while to melt a tiny amount of gelatin and is then turned upside down so that the block of product drops out. The block is then vacuum packed and stored between 0 and 4 °C. Quite frequently, this chicken product, made primarily from chicken breast meat and gelatin, is marketed as a low-fat low-sodium product, because the level of fat is only around 1–2%. A low-sodium product can easily be obtained by reducing the level of salt in the cooked chicken breast to a very low level and by adding only a small amount of salt to the gelatin solution.

## 33

# Canned retorted corned beef

Various different qualities of retorted canned corned beef are produced worldwide. As a large number of people in the world do not have access to refrigeration or even electricity at home, a shelf-stable meat product is a welcome and nutritious addition to their everyday diet. Corned beef is consumed in a variety of ways, mostly mixed with rice, potatoes, pasta or vegetables, but it is commonly also consumed cold simply with bread. Retorted corned beef is manufactured in two different ways: one process involves uncured meat whilst the other process uses cured and precooked meat material.

### **33.1 Selection of raw materials for corned beef using uncured semicooked meat**

Most, if not all, meat materials to be processed on a large scale following this method of production are handled frozen because prolonged periods of storage are only possible if meat materials are stored under freezing conditions. Quite commonly, the meat material to be processed is imported from all over the world and thus in terms of logistics it is only sensible to transport the meat frozen. Frozen or slightly tempered blocks of 50%, 65% and up to 85% CL-grade beef are used and the frozen meat material is either placed in a room overnight at ambient temperatures in order to temper it or taken straight out of the freezer prior to processing. 65% CL grade refers to the quantity of lean muscle tissue in the meat, i.e. 65% CL grade meat material consists of 65% lean muscle tissue and 35% fat. Other materials such as hearts and tongues are commonly utilized in the production of corned beef and the

inclusion level of these materials in the finished product depends largely on the level of quality of the finished product to be produced, with economical or low-cost products containing large amounts of such inexpensive non-meat materials. The bacteria count of meat materials to be processed should be as low as possible and values around  $10^3$ – $10^4$  per gram of material are commonly seen as the maximum. Because meat materials are most often handled frozen, the manufacturer has basically no impact on the bacteria count of the meat. Most boning rooms which export beef, however, operate in a hygienic way and therefore they produce meat material within low bacteria count. The meat is also packed into boxes prior to freezing, which normally results in small numbers of bacteria on the meat.

The fat present on meat must not be rancid; despite the fact that the finished product is retorted, processes such as rancidity do not completely stop and a non-typical flavour developed during retorting, originating from rancid fat, would be obtained in the finished product. These non-typical volatile flavour components remain within the can as a can is a fully sealed environment and the non-typical volatile components cannot escape as would be the case if, for example, the meat mass were to be filled into natural, and therefore permeable, casings. Frozen or tempered blocks of meat material to be processed should also pass through a metal detector prior to processing and this is common practice nowadays. As the meat is frozen, its pH value cannot be checked to determine whether the meat is DFD quality (see Chapter 4, Section 4.1) but this is of minor importance anyway as a mix of trimmings originating from different carcasses is most likely to be processed at once. Large producers of corned beef produce batches of over 500 kg per batch and, even if a small degree of DFD meat were present within a large batch, the enhanced WHC of DFD meat would only have a very small impact.

### **33.2 Precooking and blanching**

The frozen, or tempered, blocks of meat materials as well as hearts or tongues (if utilized) are cut with a frozen-meat cutter into slices of around 5 cm thickness before being placed in a hot-water bath in which the water is at a temperature of between 90 and 95 °C. A spiral or worm is most commonly in place in the cooking tunnel and the spiral transports the materials to be blanched slowly forwards. The period of time in which the materials to be blanched are exposed to heat depends on the length of the tunnel and the speed at which the spiral turns and therefore moves the meat material forwards. Generally, materials are exposed to hot water for between 15 and 20 min and a loss in weight of between 20% and 25% is obtained. The blanching process also removes a fair amount of fat which is commonly utilized separately as household cooking fat (tallow). During the blanching step, no additives such as salt or nitrite are introduced into the hot water.

### 33.3 Mixing and filling (uncured meat)

The blanched and only partially cooked materials are subsequently minced with different sized blades ranging from 8 mm to a kidney blade. Minced and still warm or hot materials are placed most commonly in a paddle or ribbon mixer. All blanched and minced meat materials are then mixed, and salt, nitrite, spices and additives such as carrageenan, guar gum, LBG and proteins (such as soy) are introduced. Nitrite is commonly introduced in the form of a nitrite–water solution to guarantee even distribution during the mixing process. If pure nitrite were added, the amount required would be so small that an even distribution within the mass would be difficult to achieve. As the nitrite is diluted in water, achieving an even distribution is much easier, which is of utmost importance as nitrite is an effective hurdle in retorted products against spores produced by bacteria such as *Clostridium botulinum*. The amount of nitrite introduced into the mass is based on the food standard in place in the respective country. As a rule of thumb, around 60% of the added nitrite can no longer be found in the retorted product as 60% has been used up during the formation of curing colour or curing flavour or oxidized to nitrate. To be more specific, if 100 ppm of nitrite per kilogram of product is permitted by law in the finished product, then around 220–240 ppm are introduced into the meat mass during mixing. However, this value should be seen as an indication only as different-sized cans and therefore different methods and programmes of heat treatment as well as the composition of the meat mass itself use up added nitrite in a different way. The optimal level of nitrite is determined quickly after a few trials, and companies follow the same recipe for years once the correct level is established. Salt is commonly added at an amount between 20 and 26 g per kilogram of mass. Spices containing spores should be avoided and spice extracts not containing spores should be used instead.

During mixing, some hot broth (obtained from blanching of the materials earlier) is added back into the minced mass and the amount of broth introduced depends to a large degree on the desired ‘quality’ of the finished product. Amounts as little as 3–5% of broth are normally added back into the mass but the amount can be as high as 10–15%. At high addition levels of broth, additives such as soy protein and hydrocolloids such as carrageenan, guar gum and LBG are introduced into the mass during mixing to support immobilization of water during retorting as well as the formation of a gel once the product cools. Added protein such as soy isolate supports the emulsification of fat during the retorting process, thus reducing the degree of fat separation during thermal treatment. Caseinate would perform better than soy protein within such an application but is generally too expensive to be introduced.

A blend of carrageenan, LBG and guar gum forms a gel after retorting as synergism is seen between the two hot-swelling hydrocolloids carrageenan and LBG. In addition, cold-swelling guar gum helps to capture any water

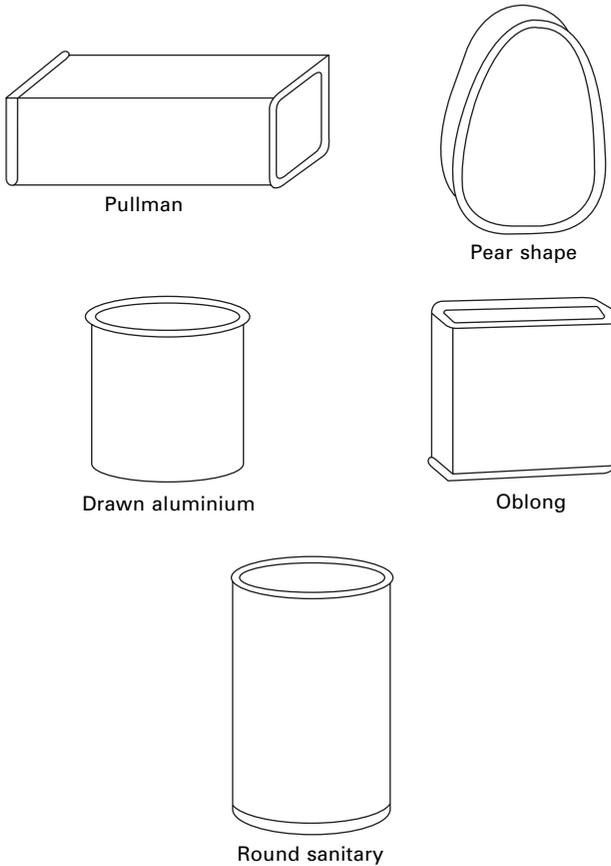
that may be released after retorting and immobilizes this water. The inclusion level of those additives varies greatly and depends to a large degree on the desired consistency of the finished product. As an indication, carrageenan could be applied from 2–3 g per kilogram of mass, LBG from 0.5 to 0.8 g per kilogram of mass and guar gum from 0.5 to 2.0 g per kilogram of mass. In most countries the finished and thermally treated product, stored at room temperature or even higher (tropical) temperatures, must still remain as a block once the can is opened and emptied out. During emptying, the block of corned beef must not fall apart into pieces or display crumbling.

The well-mixed and warm mass is subsequently filled into cans of various sizes with large cans containing 1 kg being even more frequently filled by hand whilst all other smaller cans are filled mechanically by the utilization of fully automatic filling lines. Care has to be taken that the cans used are non-rusty and clean. The lids must be properly attached so that they fully seal the can and so that no water or steam can penetrate into or out of the can during retorting as well as during cooling of the thermally treated product. Filled cans are washed, rinsed and commonly placed into cooking cages with layers of plastic placed in between each layer of cans before the filled cage is placed into the retorting oven. Retorting of products in cooking cages is the method most often used. This is a batch process as filled cages are placed in the retort oven and are removed once the retorting process is completed. Non-batch, or continuous, production is occasionally practised, in which case the filled cans pass through the retort oven on a belt or are placed on individual pallets rather than in cages. The period of time in which the can or single-layered pallet travels through a continuous retorting line depends on the type of continuous retorting system used. This can vary between 10 and 120 min. The most common shapes of cans utilized in meat products are square and Pullman base, oblong, round sanitary, pear-shaped or drawn aluminium with oblong or drawn aluminium cans often used for corned beef. Figure 33.1 shows the common shapes of cans.

Pear-shaped cans are predominantly used for pasteurized as well as sterilized hams and several different sizes of pear-shaped cans are in use. Drawn aluminium cans are also frequently used for retorted sausages such as Vienna sausages as well as meat and liver spreads whilst oblong cans are frequently utilized for luncheon meats and spam ham as well. Round sanitary or cylindrical cans are regularly applied for soups, stews and other meat-based products. Square and Pullman cans are used mostly for pasteurized meat products such as chopped ham or luncheon meat.

### 33.4 The retorting process

The retorting process or the intensity of thermal treatment, depends largely on the desired shelf life. Generally,  $F_{121.1}$  values (see Chapter 40, Section 40.3) between 8 and 14 are aimed for. Commonly, temperatures of no higher



**Fig. 33.1** Common shapes of cans.

than 118 °C are found in the retorting oven during retorting to minimize the impact of severe heat on the quality of the product. Temperatures above this level cause significantly higher levels of fat separation within the product and cause the product to obtain a crumbly texture. During the retorting and cooling processes a counter-pressure has to be applied to the cans. Pressure has to be applied to the cans as soon as the temperature exceeds 100 °C during the heating process and also until a temperature of below 100 °C is reached again during cooling, so that the lids do not bulge or the cans themselves become deformed. During cooling, the temperature is lowered from, for example, a temperature of 118 °C, by removing pressure slowly once the final or holding temperature is reached within the retorting oven.

The difference between the pressure within the can and the pressure present within the retorting oven should not be greater than 0.5–0.6 bar so that the can is not deformed and the lid does not bulge. If insufficient counter-pressure is applied during retorting, first the lid will bulge and then, in a worst-case scenario, the can might explode. The counter-pressure applied to

the can during retorting has to be the same as, or similar to, the pressure present inside the can as a result of retorting. The counter-pressure applied to the can inside the retorting oven at a temperature of 110 °C is around 1.6–1.8 bar, at 118 °C it is around 1.9–2.2 bar, and at 121 °C it is around 2.2–2.4 bar. An elevated retorting temperature of 125 °C, very rarely applied when processing meat products, requires a counter-pressure of 2.5 bar to avoid deformation of the can or bulging of the lid. Such a high temperature is generally not applied as the negative impact on the quality of the product is significant. However, the counter-pressure applied must also not be too great, nor applied too early within the retorting process as dents would form in the can simply because there was insufficient pressure inside the can once elevated levels of counter-pressure had been applied. Pressure builds up significantly inside the can at temperatures above 100 °C as the meat materials and water increase in volume. A can is a fully closed system: an increase in volume of the materials inside the can causes an increase in pressure as nothing can ‘escape’.

The build-up of pressure in a can during retorting depends largely on four variables: the temperature of the product filled into the can at the time that the can is closed, the intensity of the thermal process applied, the amount of headspace within the can and the amount of air present within the headspace. Hot materials filled into a can increase in volume to a lesser extent during retorting than products filled at a lower temperature. Hence, temperatures of around 125 °C during retorting cause a higher pressure within a can than, for example, temperatures of around 115 °C. Increased headspace normally also causes increased pressure within a can during retorting as more air expands then. The increase in pressure is reduced if air is removed from the headspace before the lid is attached to the can. The headspace in canned meat products normally varies between 5% and 10%. The volume of water present within the product also increases by around 6% during retorting as the temperature of the water is raised from 20 to 120 °C. Generally, water increases its volume by 0.6% during a 10 °C increase in temperature.

Spores of *Bacillus* spp. are killed at an  $F_{121.1}$  value of above 0.7 whilst spores from *Cl. botulinum* require a minimum  $F_{121.1}$  value of 2.6 to be safely eliminated. In practical terms,  $F_{121.1}$  values of 2.6–3.0 are utilized and the  $F_{121.1}$  value of 2.6 is also known as the ‘botulinum cook’. Other members of the genus *Clostridium* require an  $F_{121.1}$  value above 4 whilst thermophilic spores are only destroyed at  $F_{121.1}$  values above 6. Corned beef which will be stored under tropical conditions (as is often the case) commonly experiences an  $F_{121.1}$  value between 10 and 14 during processing in order to make it shelf stable for 1 year at temperatures of around 35 °C.

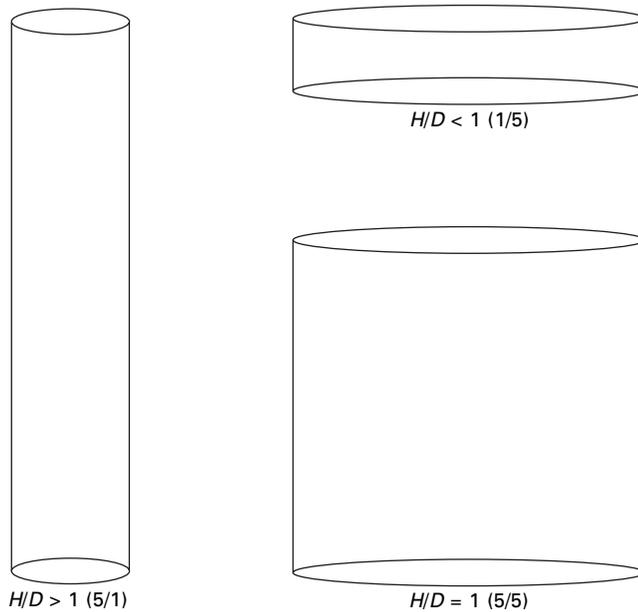
The transfer of heat via conduction into a can is dependent on the relationship between the surface area of the can and the volume of meat product inside the can. Generally, compared with large cans, small cans have a larger surface area in relation to the volume of meat inside the can and more heat is transferred into the product in a small can owing to this larger ratio of

surface area to volume. In larger cans, heat transfer takes place at a slower rate as larger cans have a smaller surface area in relation to the volume of meat inside the can.

Where cans have the same volume of filling, the transfer of heat depends on the ratio of height  $H$  to diameter  $D$ . An  $H/D$  ratio of 1 is the worst scenario from the point of view of heat transfer as this  $H/D$  ratio gives the smallest surface area in relation to the filling volume of the can. As a result, an  $H/D$  ratio either smaller or larger than 1 is beneficial.  $H/D$  ratios larger than 1 are more advantageous than  $H/D$  ratios smaller than 1; when the  $H/D$  ratio is larger than 1, the surface area is larger than it would be in a can with an  $H/D$  ratio smaller than 1, when the filling volume is constant. It can easily be mathematically proven that the surface area of cans with  $H/D$  ratios larger than 1 increases at a greater rate in relation to the volume inside the can than the surface area of cans with  $H/D$  ratios smaller than 1. Desired  $F$  values are obtained more rapidly in cans displaying  $H/D$  ratios above 1 and the thermal treatment of the product is therefore gentler. For example, a can of 5 cm in height and 1 cm in diameter ( $H/D = 5/1 \rightarrow H/D > 1$ ) has a volume of  $3.9 \text{ cm}^3$  and a surface area of  $17.3 \text{ cm}^2$ . The ratio of the surface area to the volume is 4.4:1. A can of 1 cm in height and 5 cm in diameter ( $H/D = 1/5 \rightarrow H/D < 1$ ) has a volume of  $19.6 \text{ cm}^3$  and a surface area of  $54.9 \text{ cm}^2$ . In this case the ratio of the surface area to the volume is 2.8:1. A can with a height of 5 cm and a diameter of 5 cm ( $H/D = 5/5 \rightarrow H/D = 1$ ) has a volume of  $98.1 \text{ cm}^3$  and has a surface area of  $117.7 \text{ cm}^2$ . The ratio of the surface area to the volume is 1.2:1. Cans with an  $H/D$  ratio smaller than 1 (e.g.  $1/5$ ) are widely used even though they have a smaller surface area than cans with an  $H/D$  ratio larger than 1. The first advantage of a can with a large diameter in relation to its height is that it is stable and is less likely to fall sideways once placed on a shelf in a shop and several cans can be placed on top of each other without difficulties. Secondly, cans with an  $H/D$  ratio larger than 1 have the largest surface area but the filling volume is very small, which is often not beneficial from an economic point of view. As such, cans with an  $H/D$  ratio smaller than 1 present an acceptable alternative, as they provide a large surface area as well as satisfactory filling volume. Figure 33.2 shows a can with an  $H/D$  ratio larger than 1 ( $H/D = 5/1$ ), a can with an  $H/D$  ratio less than 1 ( $H/D = 1/5$ ) and a can with an  $H/D$  ratio of 1 ( $5/5$ ).

In addition, heat is more efficiently introduced into the product when square or rectangular cans are used as they have a larger surface area in comparison with round cans containing the same volume of product. However, an increased surface area makes the can more expensive, as more material is required to make it.

During the cooling period, recontamination of the product must be avoided as cooling water is frequently contaminated. Therefore the can must be properly sealed initially. Any spores or bacteria introduced into a leaking can during the cooling period will produce an unstable product after cooling, which is compromised from the point of view of quality and safety. Once the



**Fig. 33.2** Cans with different ratios H/D of height to depth.

retorting process is completed, the cans are generally washed or polished once again and labels can be attached to them. A large quantity of corned beef, however, is filled into preprinted cans and therefore labelling of the can is not necessary. The finished product is generally placed into boxes, put on to pallets and is then ready for dispatch. Small amounts of corned beef (and also some other meat products) are processed in retortable pouch bags. When this type of packaging is used, the counter-pressure applied during the retorting and cooling processes has to be precisely controlled in relation to the pressure inside the pouch to ensure that it does not burst. This is because the stability of a bag is significantly less than that of a can.

### **33.5 Selection of raw materials for corned beef using precured cooked meat**

In countries such as the Philippines, another commonly practised method is to produce corned beef from precured materials. The vast majority of this type of corned beef is produced using lean forequarter beef of 90–95% CL grade or lean buffalo meat. The meat is predominantly purchased frozen and is then either completely thawed or tempered to a point where brine can be added to large (fist-like) pieces of meat. The bacteria count of meat to be processed should be a maximum of  $10^3$ – $10^4$  per gram of meat. Large producers nowadays utilize microwaves for tempering frozen meat and are therefore

able to raise the temperature from around  $-18\text{ }^{\circ}\text{C}$  to  $-3\text{ }^{\circ}\text{C}$  within a very short period of time without experiencing any significant thawing loss. The tempered meat is subsequently cut into large pieces for further processing, as is fully thawed meat. Following this method of producing corned beef, materials such as tongues or hearts are generally not utilized.

### **33.6 Precuring and cooking of meat**

The addition of brine to larger pieces of meat occurs in one of two distinct ways.

One way is to take tempered (still slightly frozen) or fully thawed meat and to add brine to the meat as described in Chapter 10. The level of brine added varies between 15% and 40% and the mixture is then tumbled for a period of time ranging from 30 min to 2 h. The additives introduced are phosphates, salt, nitrite and colour enhancers such as erythorbate with sugar also being commonly introduced. The phosphates utilized are ham phosphates (see Chapter 5, Section 5.1.2) as they must dissolve well within cold water and these are added at between 3 and 5 g per kilogram of tumbled mass. Salt is introduced at between 20 and 24 g per kilogram of meat whilst nitrite is added at around 150–200 ppm per kilogram of meat material. During tumbling, the brine is well absorbed and the tumbled meat material is placed in a chiller overnight at temperatures of between 0 and  $4\text{ }^{\circ}\text{C}$  for colour development.

Another method or precuring is to inject brine into fully thawed pieces of meat at similar levels of extension (15–40%). Following this method, injected material is also mixed, or tumbled, for around 30 min to 2 h before being subsequently placed in the chiller overnight. The next day, the cured meat mass is heavily cooked in water at temperatures of around  $90\text{--}95\text{ }^{\circ}\text{C}$  and a substantial loss in weight is the result. During this cooking process, the core temperature obtained within the pieces of meat is not of concern as a somewhat dry and fibrous piece of meat is the desired result.

### **33.7 Mixing and filling (cured meat)**

The heavily (over)cooked cured pieces of meat are cooled for a while before being shredded because fibres of lean muscle tissue are desired. To shred the cooked materials, the cooked meat is commonly placed in the bowl cutter and the bowl-cutter knives turn (rotate) backwards to tear apart the cooked muscle tissue. Fibrous meat is the result. The fibrous muscle tissue is placed in a mixing device and broth, obtained previously during cooking of the cured materials, is added; then all the ingredients are gently mixed. Corned beef of high quality contains only around 10–15% added broth whilst other

levels of quality have between 35 and 50% of added broth. The added broth normally contains spices and other additives such as salt, nitrite, onion, garlic, nutmeg and MSG. Products which contain high levels of added broth also contain additives such as carrageenan, guar gum, soy protein and starch so that some degree of binding is achieved within the final product after it has been retorted (see Section 33.3). The well-mixed mass is filled into cans (round sanitary, drawn aluminium or oblong), the lids are properly attached and the cans are subsequently retorted.

### **33.8 The retorting process**

The retorting process takes place in the same way as described in Section 33.4 and is most frequently based on the desired  $F_{121.1}$  value. Here once again, a counter-pressure has to be applied during the retorting and cooling phases to avoid bursting or any deformation of the can as well as bulging of the lid. Most commonly the can itself displays all the required information about the product and additional labels are also attached to the cans. If necessary, the cans are cleaned or polished once more, packed into cartons, palletized and dispatched.

## 34

# Moisture-enhanced (case-ready) and marinated meat

Around 60% of all pork sold today in retail shops in the USA is moisture-enhanced meat (MEM). The loin is the preferred cut of pork and around 80% of all loins in the USA are moisture enhanced. Pork leg meat is also commonly moisture enhanced and beef is enhanced as well, but to a lesser degree. In the USA as well as Canada, moisture-enhanced pork and spare ribs are sold as a premium product. In the UK, MEM is also produced and whole chickens, chicken breast meat as well as other parts of a chicken carcass are commonly enhanced or marinated. MEM provides benefits for both the processor and the consumer and should be seen as a means of adding value to high-quality raw meat rather than a method of covering up low-quality cuts of meat. The processor is able to sell a better product that has enhanced tenderness and juiciness, possesses better flavour and mouth feel and is also heavier. The consumer obtains a more juicy and tender cut of meat which is more succulent and tasty. In addition, the colour of MEM remains strong and natural looking significantly longer than the colour of non-treated meat. The addition of brine to MEM improves juiciness and the added moisture also prevents meat from overcooking; pork is often overcooked, resulting in a dry finished product with poorer eating qualities. Lean pork nowadays contains very little intramuscular fat and even slight overcooking of such meat results in a dry and 'tasteless' product. The addition of moisture partly compensates for the loss in juiciness previously provided by the fat in such lean meats today.

From a legal point of view, MEM in most countries has to be clearly labelled so that the customer is fully aware that the meat offered is not 'fresh'. The term 'fresh', in this context, has nothing to do with the microbiological status of the meat itself as the term 'fresh meat' by definition relates in most countries to meat which has never been treated in any way. As

MEM is treated, it cannot be sold as 'fresh meat'. MEM is commonly sold described as 'juiciness-enhanced', 'tender-juicy', 'extra-tender' or 'better-eating' meat. The list of additives applied has to be clearly displayed on the label or packaging and added water also has to be listed on the label. In most countries where percentage labelling of meat products is the practice, the label has to state the percentage of meat within the meat product which tells the customer the amount of brine introduced, or the non-meat portion of the product. Generally the meat content shown on MEM is between 90% and 93%. MEM generally does not contain added flavourings but, when terms such as 'marinated' or 'basted' are used, flavours or a surface coating have been added. Most MEM is sold on a retail level in prepacked portions. The labels of these products have to display complete information about the list of ingredients used and even the nutritional value. Strangely, in some countries, MEM sold over the counter without prepackaging is not required to be labelled as enhanced or 'treated'.

### 34.1 Selection of raw materials

The number of bacteria present on or in MEM meat prior to treatment is especially crucial as MEM is sold raw (uncooked) and the additional moisture introduced into the raw meat favours bacterial growth. The bacteria count of meat to be processed should be as low as possible;  $10^2$ – $10^4$  per gram of meat is optimal and coliforms should be present in numbers less than 100 per gram of meat. Quite often a maximum number of bacteria in the vicinity of  $10^3$  per gram of meat is the set standard prior to treatment of the meat. Other bacteria such as *Salmonella* spp., *Listeria monocytogenes*, *Escherichia coli* O157:H7 as well as *Campylobacter jejuni* should not be present in 25 g (i.e. it should not be possible to detect any of these bacteria in a 25 g sample of meat; this phrase often causes confusion as it does not indicate that there should be a zero presence of the bacteria, simply that no bacteria should be detected in a 25 g sample). *E. coli* should also be present at numbers less than 10 per gram of meat. The meat to be processed should be well chilled and a temperature of 0–2 °C is optimal.

PSE pork (see Chapter 4, Section 4.1) caused to a large degree by stress prior to slaughter has to be avoided, as much as possible. Halothane-positive pigs should not be processed for MEM as they are more prone to developing PSE-character meat. Animals should also be handled properly prior to and during slaughter to reduce the degree and severity of PSE. Stunning of pigs utilizing carbon dioxide (CO<sub>2</sub>), for example, compared with electrical stunning is a gentler method and reduces the likelihood of PSE meat.

Pork nowadays commonly displays only 2–3% intramuscular fat (marbling fat) and dry and fibrous meat, especially in cuts such as pork loin, is the result of this low fat content. Breeds such as Landrace and Yorkshire generally exhibit less intramuscular fat whilst other breeds such as Duroc display a

higher level of marbling fat. Duroc pork is therefore more succulent by nature but the elevated levels of natural fat are commonly not desired by the consumer. Boar meat should be avoided by producing MEM owing to its urine-like smell (the presence of androstenone, testosterone and scatol); castration of the boar several weeks before slaughter would remove this boar taint. Cold shortening (see Chapter 4, Section 4.5) during cooling of the pig carcass should be avoided even though fast chilling of a pig carcass would reduce bacterial growth and the level of PSE, as no additive or other subsequent treatment can reverse cold shortening shortfall once it has occurred.

Pork meat to be processed should not have matured for more than 1–2 days because pork has strong post-mortem enzyme activity, thus leading to a quick increase in pH value. A pH value between 5.5 and 5.9 is seen as optimal; this provides a good balance between increasing WHC (moving away from the IEP at pH value 5.2) but still being well below 6.2–6.3 where bacterial growth starts to take place at a fast rate, thus resulting in reduced shelf life of the product. Most countries in the world permit only fresh meat to be processed into MEM and frozen or thawed frozen meat cannot be used. When thawed meat is permitted and is going to be processed, the temperature applied during thawing should not exceed 5 °C as elevated bacterial growth would occur. Thawing in general must occur under hygienic circumstances to keep the bacteria count as low as possible. The MEM technique is not applied as frequently to beef as to pork. DFD beef (see Chapter 4, Section 4.1) must not be processed as DFD meat has a dramatically shortened shelf life. This is because it has experienced incomplete rigor mortis, and therefore significantly reduced acidification and the high pH value seen in DFD meat supports microbiological spoilage. The dark colour seen in DFD meat is not attractive either.

## 34.2 Selection of additives

Additives frequently applied to MEM are phosphates, salt and lactate. Phosphates (see Chapter 5, Section 5.1.2) introduced into the brine must be water soluble as only fully dissolved phosphates can act on protein within the injected piece of meat to immobilize or retain added water.

The level of phosphate applied varies between 2 and 4 g per kilogram of injected meat (0.2–0.4%) and the pH value of the phosphate blend introduced should be around 8.7–9.2. Phosphate blends, or straight phosphates, with pH values above 9.4 raise the pH value within meat significantly, thus supporting microbiological growth. They can also possibly give the product a soapy (alkaline) taste. Salt is introduced into MEM at 4–8 g per kilogram of meat to enhance the natural flavour of meat itself as well as to increase the ionic strength. This supports swelling of protein as salt acts synergistically with phosphates to immobilize added water (see Chapter 8, Section 8.2.1).

The introduction of lactate (see Chapter 5, Section 5.2.2) between 25 and 32 g per kilogram of injected meat, or 2.5–3.2%, has a positive impact, extending the shelf life of the product as well as adding flavour and juiciness and also enhancing the colour of the injected meat despite the addition of water. Lactate also helps to reduce the amount of purge within the finished product. The colour of fresh meat, especially pork, fades quite quickly and in particular the surface frequently has a dull appearance after a short while. The addition of lactate strengthens the natural red colour of meat and also maintains a shiny surface. Introducing lactate raises the pH value slightly which supports the reduction of metmyoglobin to reduced myoglobin which can turn again into oxymyoglobin in the presence of oxygen, thus resulting in a stronger meat colour. The impact of lactate on the maintainance of an appealing colour is often seen as more important than its impact on extending the shelf life. This is because fading in colour, which results in an unsellable product, occurs much sooner than microbiological spoilage does. Potassium lactate is frequently utilized instead of sodium lactate as it does not contribute to a salty taste within the product.

Cold-swelling gums, or thickeners, such as guar or xanthan gum (see Chapter 5, Sections 5.3.1 and 5.3.2) as well as cold-swelling modified starches are generally not applied even though their application would make sense from a technological point of view. As the finished product is sold in an uncooked way, a thickener within the product would support retention of added water. However, several countries do not permit the application of such additives as higher levels of extension could be easily achieved. This goes against the original concept of MEM: adding real value to meat rather than seeking high levels of extensions. In extreme cases (not the general concept of MEM in most parts of the world), meat is ‘enhanced’ between 40% and 60% and all types of cold swelling material such as xanthan and guar gum as well as starches are utilized. Furthermore, such highly ‘enhanced’ meat also commonly contains carrageenan to achieve a high cooking yield with the brines used being of high viscosity in order to retain high levels of added water.

Occasionally, injectable flavours are part of the injection brine as well. The introduction of flavour into the brine, and subsequently into the product, is most often classified as part of ‘marinating’ meat, however, rather than ‘enhancing’ meat. Generally, enhanced meat may legally contain phosphates, salt and lactate and must be termed marinated meat as soon as flavours are added.

### **34.3 Manufacturing technology**

Brine is prepared by dissolving phosphates first in cold water to ensure that all the phosphates are completely dissolved. The water used must be of drinking (potable) quality and should be at a temperature between 0 and

2 °C. If cold water at these temperatures is not available, ice can partly replace water. Once all the phosphates are fully dissolved, salt is added to the brine and it is mixed until all the salt has dissolved. Finally, lactate is introduced into the brine. The finished brine should be at a temperature from -1 to 2 °C. This is essential since the 'temperature' is of great importance as a hurdle to ensure that the MEM has the desired shelf life. A brine for a 10% injection contains around 3% phosphates, 6% salt and 30% lactate and the exact level of additives can be calculated on the basis of the mathematical formula shown in Chapter 8, Section 8.3. As the product is not heat treated, the level of injection is the same as yield and a 10%-injected meat results in 110% yield. Brine should be freshly prepared just prior to use and the brine once used, containing traces of blood and proteins among other substances, must not be stored overnight and utilized again next day as the risk of bacterial growth is too high. The level of injection in MEM varies generally between 8% and 12%. Injection must be accurate because these concentrated brines contain high levels of salt as well as phosphates. If meat is overpumped, an acceptable level of salt and phosphates within the processed meat is quickly exceeded. Consistent levels of injection are the key to consistent product quality and this requires the utilization of well-functioning injectors. In addition, injectors utilized must be kept spotlessly clean all the time prior to and after use so as not to introduce bacteria directly into the muscle tissue being injected. From a nutritional standpoint, MEM has a lower nutritional value than untreated meat owing to the addition of water. The addition of salt also raises the level of sodium, and the level in the treated meat, depending on the amount of salt added, can be up to eight times higher than in non-treated meat.

Following injection, meat is occasionally tumbled for around 30 min which supports the distribution of brine inside injected meat as well as increasing the tenderness of muscle tissue. Tumbling must not last for too long, however, as the large pieces of meat can be torn apart. Most commonly, injected meat is not tumbled and is packed immediately after injection. Tumbling generally increases the ability to immobilize added water, thus reducing the amount of purge seen within the packed product over a period of time. The additional processing step of tumbling, however, increases the cost of the process at the same time. Applying spices or herbs to the surface of the injected piece of meat for visual appearance is often classified as 'marinating'. Therefore, spices are not permitted to be added to MEM in most countries.

Injected meat, tumbled or not, is most commonly vacuum packed into shrink bags and dipped for a few seconds into hot water at 85–90 °C. The dipping process serves the purpose of shrinking the bag which aligns itself very tightly around the packed piece of meat resulting in an attractive appearance. Because of bag shrinking, as well as the presence of a vacuum within the bag, some pressure is applied to the surface of meat and this helps the retention of injected brine inside the meat. Finally a hot temperature

applied to the surface of injected and packed meat (even for only a very short time) during the dipping process reduces the possibility of an elevated bacteria count on the surface. The bacteria count could have risen because of unintentional recontamination during packing, thus possibly reducing shelf life. MEM can also be modified atmosphere packed. The packaging contains around 80% oxygen (O<sub>2</sub>) as well as 20% CO<sub>2</sub> because high levels of oxymyoglobin result in an attractive colour for a prolonged period of time.

The packed material is stored at 0–2 °C; aerobic spoilage bacteria such as *Pseudomonas* spp. grow very slowly at these temperatures, and the growth of Enterobacteriaceae is also sufficiently slow at such low temperatures. Most commonly, lactic acid bacteria such as *Lactobacillus* spp., *Leuconostoc* spp., *Pediococcus* spp. and *Streptococcus* spp. dominate the microflora within MEM rather than Enterobacteriaceae. The major potential pathogens in MEM are *Salmonella* spp., *E. coli* O157:H7, *Clostridium* spp., *L. monocytogenes* and *Campylobacter* spp. The dominant spoilage bacteria within MEM are coliforms, lactic acid bacteria, Enterobacteriaceae, *Pseudomonas* spp. as well as *Brochothrix thermosphacta*.

The labelling of MEM often must state clearly that the product needs to be heat treated. Cooking guidelines are often given as well, e.g. guidelines to ensure that a temperature of at least 72 °C is obtained in the core of the meat. Meat with a high pH value (above 6.2), despite being properly cooked, can show the phenomenon known as ‘persistent pink’. This is because the iron core in myoglobin is protected by the high pH value and the meat, despite being fully cooked, still displays a touch of pink colour instead of the desired grey colour which results from denatured metmyoglobin or myoglobin. Another reason for a touch of unwanted pink colour within the product can be the presence of nitrate and/or nitrite within water utilized for the preparation of brine given that 3–4 ppm of nitrite per kilogram of meat is sufficient for a touch of pink colour. MEM is also commonly sliced into portions and a very high standard of hygiene has to be maintained in order to achieve the desired shelf life.

### 34.4 Marination of meat

Meat is marinated all over the world and a huge variety of very attractive tasty products of different colours, shapes and sizes are offered. All the different types of meat such as pork, beef, fish and chicken are used and the large majority of marinated meats are ultimately heat treated by grilling or roasting. Meat to be marinated is commonly cut into portions as an enlarged surface area makes the marinade work more effectively. Some meat material to be marinated such as pork spare ribs are also precooked before being marinated in order to extend the shelf life of the marinated product.

One way of marinating meat is to add a dry-powder mix containing salt as well as desired spices such as garlic, pepper, onion and chili among others.

Salt is applied to the marinated meat at a level of around 1.3–1.5%, or 13–15 g per kilogram of meat, because the loss in weight during grilling or frying leads to an increase in salt within the cooked product to levels of around 1.8–2.0%. In salt–spice mixtures, the salt is usually encapsulated as non-encapsulated salt would draw moisture from the marinated piece of meat. Tenderizers such as papain (see Chapter 3, Section 3.2) are occasionally part of the spice mixture as well. Another method of marination is to prepare a liquid blend from dry powders mixed with water or oil, or a mix of water and oil. Generally, around 20–30 g of powder marinade are mixed with 70–80% of oil or water and around 100 g of liquid marinade is applied per kilogram of meat. The level of salt within the liquid marinade is around 13–15% and, as around 100 g of liquid marinade is applied to 1 kg of meat (which equals 10% of marinade), the level of salt in the marinated meat is once again around 1.3–1.5%. Quite often, phosphates are present in powder blends used to marinate meat, especially if the blends are to be mixed with water. This is because the introduction of salt and phosphate activates protein, thus supporting the immobilization of added water. The viscosity of a prepared marinade is controlled by guar or xanthan gum. The viscosity should be at a high enough level to delay run-off greatly.

Meat can also be marinated by applying a liquid marinade, which can be a water–oil–spice emulsion or only based on oil. Many water–oil marinades have a pH of around 4.0 which makes them microbiologically stable but does not give the marinated meat a sour taste. A reduction in pH value in marinades, commonly a result of the introduction of 2–3% of a 10% vinegar (containing acetic acid) is only possible by water–oil marinades because oil only does not support dissociation of acids and no H<sup>+</sup> ions would be released to cause a fall in pH value. Sourness caused by the introduction of acids has a beneficial effect on connective tissue within marinated meat as collagen swells if exposed to a sour environment, thus enhancing tenderness as well as juiciness. Within liquid marinades, salt is added in the form of common salt, rather than encapsulated salt. Marinating meat with a sour marinade with a pH of 4.0–4.5 has little impact on the tenderness of the meat fibres as tenderness is brought about by enzymes such as cathepsins and calpains (see Chapter 3, Section 3.1). Another possible method of regulating the pH value of a marinade is the addition of citric or acetic acid at a level to reach the desired pH value within the marinade.

Water–oil-based marinades are commonly stabilized by the addition of cold-swelling gums such as xanthan and guar gum as well as some milk proteins. Within water–oil-based marinades a controlled high level of viscosity is desired as no sedimentation of spices and demixing between oil and spices must take place over time. Oil-based marinades are frequently made from a mixture of oil in and hardened fat to achieve the desired viscosity as well as to prevent demixing during storage. In both types of liquid marinade, 100 g of marinade are often applied per kilogram of meat and the level of salt applied per kilogram of marinated meat is around 1.4–1.5% (with salt being

part of the liquid marinade at around 15%). Spices introduced in liquid marinades are commonly treated to reduce their bacteria count, and spice extracts, as well as oleoresins, are frequently utilized as well. Lactate (see Chapter 5, Section 5.3.3) is frequently added to marinated meat in order to extend shelf life.

Quite commonly, when larger pieces of meat are marinated, brine containing phosphates and salt is injected into the piece of meat before marination. The level of extension as a result of injection is usually between 10% and 25%. Much more extreme levels of extensions (40–60%) are occasionally practised in some parts of the world. Brines for higher levels of extension contain, besides phosphates and salt, various different types of hydrocolloid such as guar or xanthan gum as well as proteins and modified cold-swelling starch.

Once injected, the meat is tumbled for a while to absorb and immobilize the brine fully as well as to create some degree of activated surface protein before spices and herbs are applied to the surface.

Chicken is an excellent type of meat to marinate as it has a bland flavour on its own and therefore accepts many different types of flavour well. Whole rotisserie birds are injected at levels of between 8% and 20% with brine containing phosphates, salt, some flavour as well as guar gum to increase viscosity in order to delay the formation of purge. The largest drip loss in injected whole birds takes place around 10–15 min after injection as the phosphates and salt have not yet had an impact on protein in this short period of time. As a result, additives such as soy protein, guar gum or xanthan gum as well as injectable cold-swelling starch significantly reduce loss in weight during the time immediately after injection. Needles on the injector have to be kept blockage free and clean. Specially designed injectors for injecting poultry should be used, because birds, or parts of a chicken, are small and fragile and great damage can be done by working with 'rough' injectors which can even crush bones during injection. Increasing the cooking yield in whole rotisserie birds can be achieved by introducing soy proteins and also slightly increasing the level of injection at the same time. The inclusion of soy, however, must still be economically viable and it must also be taken into account that large numbers of consumers are not willing to purchase roast chicken containing soy protein.

Honey is a material frequently added to marinades for its distinctive flavour and contribution to colour as it is broken down in the Maillard reaction (see Chapter 4, Section 4.13) under the impact of heat. Honey is sweeter than sucrose and its flavour intensity relates to its colour; darker-coloured honey has a stronger flavour. Honey in a marinade does not interfere with brine absorption (if meat is mixed or tumbled with marinade) and gives meat products a shiny glossy appearance after heat treatment. If introduced into injection brines, honey should be premixed with some warm water first to dissolve the honey fully before being added to the icy cold injection brine. This is because honey that is introduced directly into icy cold water is poorly soluble. In addition, honey is also an excellent antioxidant as floral nectar contains several antioxidative substances.

A quite unique way of marinating meat is practised in Germany. Following this method, beef cuts such as rump, even from cow, are placed in a sour solution made from water, wine, vinegars, salt and spices (sauerbraten). Boneless meat is placed in this sour marinade for several days under chilled conditions and the structure of the collagen loosens owing to the impact of acidity. Elevated levels of moisture are also gained during the soaking process as a result of swollen collagen and the result is a juicy and succulent product after roasting in the oven.

## 35

# Casings and packaging material

### 35.1 Natural casings

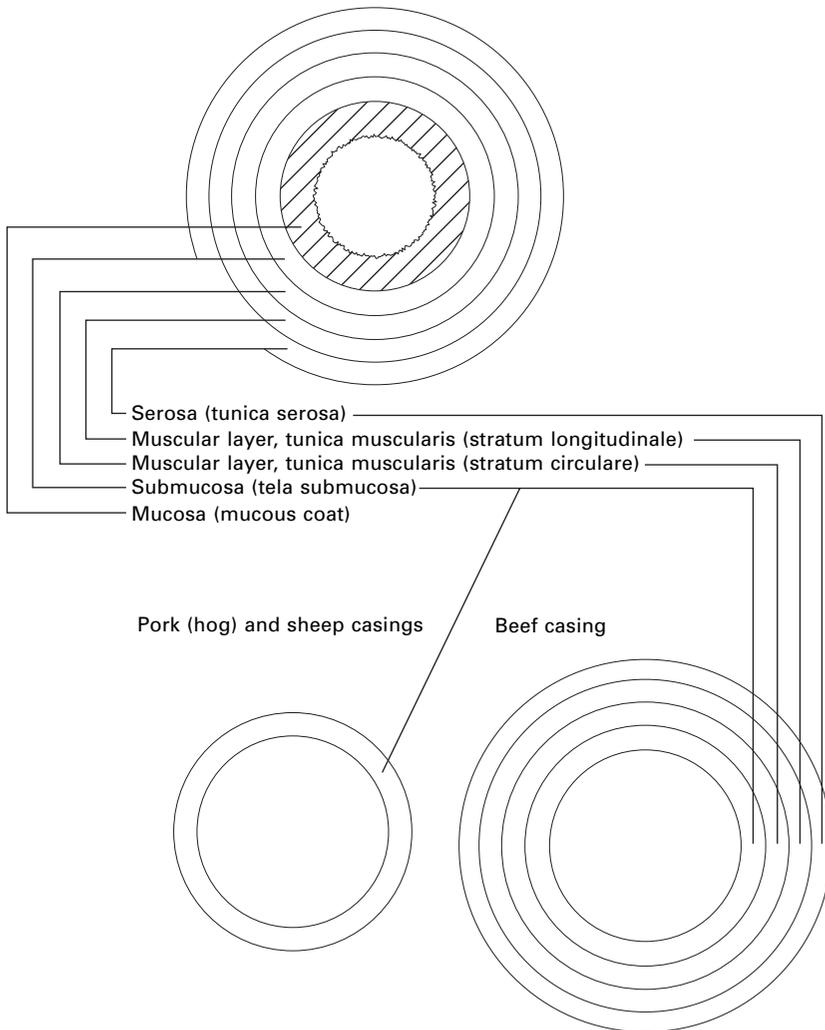
A large number of meat products such as cooked sausages (frankfurters), liver sausages, salami and ham products are always filled into casings. Other meat products such as brawns, meat jellies and blood sausages are commonly filled into casings as well. Casings keep the meat product in shape, act as a barrier against external influences such as UV light and moisture and are also a factor in the marketing and sale of the product. An attractive casing showing a company's logo, for example, could promote sales.

The casing of a meat product makes up around 1% of the finished item and its primary function, as mentioned above, is to give the product a certain shape and to ensure that this shape is maintained. Natural casings from pigs, sheep, horses and cattle have been used in the production of meat products for thousands of years. They are highly permeable to smoke and moisture and therefore the risk of water or fat separation in products filled into natural casings is reduced. Natural casings cohere very well to the meat mass filled into the casing and therefore they do not separate from the meat mass, as might occur, for example, during drying of a salami. Natural casings also shrink well and contribute to the 'snap' of cooked sausages such as frankfurters. The fact that these casings are a '100% natural product' can also be used for marketing purposes, and the natural casings give a meat product a distinctly old-world appearance. Brawn filled into pork stomach, for example, would be recognized by the consumer as a very traditional product.

Natural casings are often made from the small intestines, which are made up of several layers. The innermost layer of the gut wall is called the mucosa and contains glands which play a role in secretion and absorption in the gut

and the digestion of food. The next layer (counting from the inside of the gut to the outside) is the submucosa, which is predominately made up of connective tissue (collagen), and this layer strengthens the gut wall. The submucosa is followed by a layer of circular muscle tissue and then a layer of longitudinal muscle tissue. The outermost outer layer is the serosa, which is mainly made up of collagen and elastin, but fat is also present on the outside of this layer. Figure 35.1 shows a cross-section of an intestine.

Beef casings used in the production of meat products originate mostly from the oesophagus or weasand, small and large intestines, caecum (bungs) and bladder. Weasands from cattle are usually used for large-diameter sausages and bladder.



**Fig. 35.1** Cross-section of an intestine.

and the length of a weasand is around 50–60 cm. Casings from the small intestines of cattle are commonly known as rounds or runners whereas casings originating from the large intestines of cattle are known as middles. The total length of all small and large intestines together is around 20 times the length of the body of a cow. The small intestines of cattle, from which come rounds or runners, are around 35 m in length and have a diameter of 4–6 cm. Before use, beef rounds are commonly flushed with water, inversed (turned inside out) and the mucosa and the fat connected to the serosa are removed. Casings from the small intestines of beef, therefore, contain the submucosa and both layers of muscle tissue and the serosa are therefore much thicker than pork runners which consist only of the submucosa, as all other layers are removed. Beef runners are sold in hanks, with one hank being 100 yards or 91.4 m in length. Beef bungs are made from the blind gut or caecum of cattle, which connects to the small and large intestines. Bungs are around 70 cm long and 10–15 cm wide. Beef bungs are treated more or less in the same way as middles (see below). Beef bladders, on the other hand, are washed, inversed and inflated with air or salted before use.

Before use, beef middles are separated from the ruffle (fat associated with the intestines) and then flushed with water. Any fat is trimmed off and they are then inversed, slimmed (i.e. the layer of mucosa is removed) and salted. Certain sections of beef middles are known as the ‘straight casings’. These include the narrow end, wide end and fat end of the middles, with the fat end being the part most commonly used.

Pig casings have a total length of around 25 m and parts such as the stomach, the small intestines (also known as the runners, rounds or hog casings), the large intestines such as the cap (caecum) and middles, the terminal end of large intestines (bung) and the bladder are used in the production of meat products. When pig stomach is not being used for filling sausages, it is scalded, well cleaned and subsequently usually processed further for soups or introduced into traditional Italian mortadella once it has been cooked. When it is utilized as a casing for meat products, it is washed and salted. Pig rounds, from the small intestines, are around 18 m in length. To make rounds, the small intestines are separated from the ruffle and all intestinal contents are removed either by hand or by machine. The emptied intestines are then treated with a mucous remover and are de-slimed (the layer of mucosa is removed). If the intestinal contents are removed by machine, machines with a set of strippers or rollers remove the mucosa, both layers of muscle tissue and the serosa from the casing. Finally, only the submucosa from the small intestines remains as the material to be used as casing for sausages. This is then salted. The removal of the mucosa used to be carried out in the past by hand and, to remove the mucosa as well as the two layers of muscle tissue, the casing used to be soaked in water at around 25 °C overnight with the casing being inverted prior to soaking. Both layers would become very soft and tender and could be removed afterwards by hand easily. Pig rounds, or runners, exhibit a diameter from 28 to 42 mm and are sometimes even larger, depending on the age and breed of the animal.

The processed pork caecum is known as the cap, and the middle section of the large intestines is known as the middles. The first and large section of the large intestines of pigs is normally not used in the production of sausages. To be used as casings, pork middles are separated from fat, flushed well with water and inverted. Mucosa and serosa are removed, leaving both layers of muscle tissue and the submucosa. The middles are then finally salted. Pig bungs, the terminal end of the large intestine, are around 1 m in length. They are thoroughly flushed, slimmed (i.e. their mucosa removed), inflated for grading and salted. Pig bladders to be used as casings are emptied and excess fat is removed. They are then inverted before they are salted or inflated by air and dried.

Both hog and sheep casings are sold either as 'selected' or 'unselected' casings. These terms refer to the diameter of the casings in a hank (a bundle of casings) and selected casings all have a diameter within a narrow and specified range. In a selected hank of casings, around 90–94% must be within the diameter specified. They are significantly more expensive than unselected casings. The diameter of unselected casings varies hugely and typically only around 60–70% of all casing material within a hank is within the mentioned diameter. To grade a casing according to its diameter, the casing is inflated with air or water and then the diameter can be determined.

Casings from sheep are divided into rounds, caps and straight casings. Commonly only sheep rounds (originating from the small intestines) are used for the production of sausages such as frankfurters, but sheep caps are occasionally utilized for salami (inverted and with the mucosa removed). The sheep small intestines or rounds are separated from the ruffle and the contents of the intestines are removed. The mucosa, both layers of muscular tissue and the serosa, are then removed from the emptied casing, as only the submucosa is utilized as a casing. The material is finally salted. Sheep casings are also sold in hanks, with one hank being 100 yards or 91.4 m long. The diameter of sheep casings varies commonly between 16 and 28 mm. Cooked sausages such as frankfurters and Vienna sausage are often filled into this type of casing. Fresh sausages are also occasionally filled into natural sheep (and hog) casings.

During salting, natural casings are heavily exposed to salt. Typically 40–50% salt is added to the cleaned and prepared casing. Stored in containers at around 4 °C, salted casings have an essentially limitless shelf life as a result of the cold storage temperature and especially because of the extremely high concentration of salt, which reduces the  $A_w$  value and inhibits growth of bacteria. Prior to use for the manufacture of sausage, the casings are washed well in order to remove all salt. The thoroughly washed casings are placed in hand-warm water in order to increase the elasticity of the casing for easy filling and linking. Natural casings today are also available preflushed in salt brines containing around 15% salt and are already pretubed (shirred) for better efficiency during the filling process. The time taken to fit the casing on to the filling pipe (stuffing horn) is shortened considerably if shirred natural casings are used. Table 35.1 shows recommended levels of

**Table 35.1** Recommended levels of bacteria per gram on natural casings (levels vary from country to country)

	Bacterial level per gram	
	Optimum	Maximum
Aerobic bacteria	$< 1.0 \times 10^5$	$4.0 \times 10^6$
<i>Staphylococcus aureus</i>	$< 1.0 \times 10^2$	$1.0 \times 10^3$
Enterobacteriaceae	$< 1.0 \times 10^5$	$7.0 \times 10^3$
Sulphite-reducing spores of <i>Clostridium</i> spp.	$< 1.0 \times 10^2$	$7.0 \times 10^2$

bacteria per gram on natural casings. These guidelines vary from country to country.

### 35.2 Cellulose casings

Cellulose casings are used worldwide for the production of meat products such as skinless hot dogs and frankfurters, spreadable raw sausage, cooked ham and mortadella. Cellulose casings are made from raw cellulose, which is first treated chemically to obtain a pulp-like mixture. Additional chemical treatment with an alkali then results finally in a material known as viscose which is a honey-like, gluey and yet still runny material. Viscose is not a different material, but rather cellulose present in another form and therefore it is true to say that the raw material utilized for the manufacture of cellulose casings is pure cellulose. The hot and gluey viscose is subsequently extruded to form the desired diameter. Cellulose casings are generally non-edible and are available with a dull or shiny (glossy) appearance depending on the product to be produced. This type of casing also clings very little to the meat product filled into it and can be smoked. Cellulose casings are occasionally soaked prior to being filled for around 30 min in lukewarm water whilst others can be filled without being soaked. Printed casing material should be soaked for 50–60 min as that the part of the casing material under the print would not be sufficiently exposed to water after soaking for 30 min compared with the non-printed casing material. During the manufacture of skinless sausages it is vital that a stable and firm emulsion is obtained in order to form a second skin underneath the cellulose casing. This type of casing does not reshrink to a large extent and therefore it is easy for fat and/or water to separate. Once the sausage is cooked and fully chilled, the casing is cut longitudinally, removed from the sausage and discarded. Small-diameter cellulose casings frequently include a water-soluble colour which is transferred on to the surface of the meat product during moist thermal treatment. Large-diameter cellulose casings with great stretchability are available as well for products such as mortadella and beer sausage.

### 35.3 Collagen casings

Edible and inedible casings can be produced from collagen extracted from the corium layer of beef hides and demonstrate more or less the same organoleptic properties as natural casings. The corium layer is the middle layer of beef hides. It is placed in a high-pH solution so that it swells and takes up a large amount of water. The swollen material is then washed and the controlled addition of acids as well as application of different temperatures result in a perfectly swollen raw material. The material obtained is minced and water, cellulose and acids are added. All materials are cut extremely finely in order to obtain a homogeneous and pumpable material. Within this gel the added cellulose functions as a glue when the gel is extruded into casings. Different extrusion techniques determine the properties of the casing which finally passes through a solution of salt prior to being dried. Commonly the next processing step when producing small-diameter cellulose casings is to shirr the casing into 'slugs'. The 'slugs' are then placed in cartons. During shirring, the straight tube of casing is compressed over a horn and therefore there is significantly more casing material (in metres) in a slug than in a non-shirred section of casing. The slug of casing will ultimately be placed over the filling pipe of the filling or stuffing machine prior to being filled. Edible collagen casings are widely utilized for fresh and cooked sausages as they produce a tender sausage skin and contribute positively to bite, or snap, of the sausage as well. Sausages filled into cellulose casings should not be thermally treated with steam or in a hot-water bath above 80–82 °C since splitting of the casings occurs frequently at and above those temperatures. Different strengths of cellulose casings for fresh sausages are available, displaying more or less resistance to heat during frying and grilling of the sausage. Inedible collagen casings are used for larger-diameter sausages. They have the characteristics of both natural and artificial casings as regards uniformity, strength and shrinkability. Inedible collagen casings are removed from the meat products prior to consumption.

### 35.4 Waterproof (non-permeable) casings

Waterproof casings are becoming increasingly popular as no cooking loss is obtained during heat treatment in products filled in this type of casing. Waterproof casings can also function as a form of packaging, or even the final packaging of a product, at the same time as functioning as a casing. The list of waterproof casings available today is almost endless and ranges from single- up to five-layer casings. Monolayer waterproof plastic casings are extruded to the desired diameter from a single material, most commonly polyamide. During the production of the casing, the formed tube is stretched biaxially (horizontally as well as vertically) which gives the casing reshinkability. Plastic casings that are not biaxially stretched do not have

good reshrinkability, which can lead to water and/or fat separation in meat products because no pressure is applied to the thermally hot meat product during the cooling phase. Monolayer plastic casings exhibit good barrier characteristics against oxygen (O<sub>2</sub>) (air) as well as moisture. Multiple-layer plastic casings, however, generally display better barrier characteristics and are also more robust (thicker) than monolayer casings. Nevertheless, the barrier characteristics of a monolayer casing can be as high as those of a multiple-layer casing as this depends on the material utilized in the production of a monolayer casing. The production of multiple-layer casings is a high-technology process. It is not simply the case that several different materials are mixed together and the mixture is then extruded; rather each layer of material is placed on top of the layer underneath in a continuous process that creates three to five distinctive layers on top of one another. Materials such as polyamide and polyethylene are commonly used in the manufacture of multiple layer waterproof casings. The reshrinkability of a plastic casing as a result of biaxial stretching is not limitless and a reshrink of around 8–12% is the absolute maximum. The ability of a plastic casing to shrink during cooling and to apply pressure to the product is of importance to obtain a wrinkle-free product as well as to reduce the risk of water and/or fat separation, as could happen if there is a lack of pressure on a thermally treated meat product as it cools. Leading manufacturers of plastic casings also offer 'smokeable' plastic casings which could seem puzzling as plastic casings are, almost by definition, waterproof, thus not allowing anything to penetrate into or out of the product. However, these smokeable plastic casings are produced in a way that, when smoke is applied at high temperatures of around 75–80 °C, as well as high levels of humidity for a prolonged period of time, a small amount of smoke penetrates through the casing. The final product then exhibits a lovely smoke flavour but no smoke colour.

Other attributes desired from a waterproof casing are that it is easy to handle during filling, that it exhibits a constant diameter, that it is easy to peel and that it is not harmful to human health when used as a food contact material. Automatic filling lines must be able to handle the casing well and printing of the casing must also be possible. Waterproof casings of almost any diameter are commonly processed in shirred form for large-volume production. The majority of waterproof casings require soaking prior to filling in hand-warm water for 30–60 min, whilst some others can be filled without being soaked. Most waterproof casings are filled up to diameter and are therefore not overfilled, as is the case when fibrous casings are used (see Section 35.5). To be more specific, a 90 mm casing is filled up to 90 mm for optimal performance. For purposes of economy, a waterproof casing can act not only as a casing but also frequently as the final packaging of the product. All the information needed about the product such as the list of ingredients, bar code, best-before date, nutritional value and allergen statements can be printed on to the casing. An endless variety of colours of waterproof casings

are found, with the colour normally being introduced into the polyamide material before it is extruded.

### **35.5 Non-waterproof (permeable) casings**

Besides natural casings, fibrous casings are widely used for meat products. These are made from cellulose reinforced with a fibre material such as paper for increased strength. To produce fibrous casings, paper is folded into a tube with the width of the paper determining the diameter of the tube and ultimately the diameter of the casing. The paper utilized is greatly resistant to heat and moisture and can be compared with paper used for the production of tea bags. Once the paper has been folded into tubes, the paper tubes are run through a bath of viscose and colour (if the casing should be coloured) followed by several baths of acids and alkalis to 'set' the casing. The last bath contains a 'softener' which keeps the finished casing soft and elastic despite the fact that the dried casing contains only around 5–7% moisture. After having passed through several baths of acids and alkalis, the moist casing is blown up to diameter, dried (at around 140–180 °C), flattened and put on rolls. The application of such high temperatures results in a casing material with a very low bacteria count. It is either sold as a roll or converted further in various processing steps such as printing, presticking (introduction of tiny holes into the casing in a grid pattern to improve its drying properties and smoke absorption) or shirring.

Large manufacturers of casings can print casings on both sides with up to eight colours with printing quality as good as a photograph. Printing of a fibrous casing is quite a difficult task because the print present on the casing must block neither movement of moisture out of the product nor movement of smoke into the product. Special methods of printing are applied to ensure that, even underneath printed areas, movement of air or penetration of smoke into the product is possible. Fibrous casings are generally soaked for around 30 min in lukewarm water prior to filling so that the material becomes soft and elastic. Printed material should be soaked for 50–60 min.

For simplicity, there are fibrous casings on the market which are already presoaked and therefore can be filled immediately without any further soaking required. Filling of fibrous casings takes place in such a way that the diameter of the casing itself is exceeded by around 7–10% once the product is filled. For example, a casing of 60 mm diameter is filled to around 65 mm. The overfilling secures a wrinkle-free product as well as making full use of the volume of the casing.

Fibrous casings are commonly impregnated with a substance inside the casing which determines the cling or adhesion of the casing to the meat product itself. Some fibrous casings are treated in a way that the casing clings strongly to the meat products. This is desired in production of raw fermented salami as the casing has to shrink with the product without becoming

loose. So that the casing clings well, a layer of protein is applied to the inside of the casing. The layer of protein binds strongly with activated protein from the meat product filled into the casing.

On the other hand, fibrous casings can be treated on the inside with a releasing agent which reduces cling between the casing and the meat product, securing easy peeling of the finished product. This is especially of importance for meat products which will be sliced. Some fibrous casings are not impregnated with any substance on the inside and therefore they cling slightly to the product. Fibrous casings used for the manufacture of raw fermented salami can also have mould-inhibiting properties. Sometimes various acids are introduced into the casing and, as a result, unwanted growth of mould on salami during drying is reduced.

Large-diameter fibrous casings, predominantly utilized for cooked ham products, are prestuck and little holes can be seen in the casing in a grid pattern. The holes allow the surface of a ham to dry more rapidly and to absorb smoke more efficiently at the same time. In addition, smoke-coated fibrous casings (casings with a layer of smoke on the inside of the casing) are available. If these casings are used, the smoking cycle can be omitted, thus shortening the processing time significantly. These casings are not soaked prior to being filled because the layer of smoke would be washed off during soaking. Products filled into smoke-coated fibrous casings are dried as the first processing step (no moisture is applied) to ensure proper and full transfer of smoke from the casing on to the surface of the product. Items such as cooked hams or cooked sausages are subsequently commonly treated with steam until the desired core temperature is obtained. Following such treatment, the finished product displays a nice and even smoke colour although it has never been smoked. Heat-treated products filled into a fibrous casing are generally showered for a short while to avoid the formation of wrinkles as the product inside the casing shrinks once thermal treatment is completed. In order for the casing to shrink with the product, moisture supplied by showering is required. There are some specialty fibrous casings on the market. Honeycomb casings, for example, have a netting attached to them which results in an extremely pleasant visual appearance of the finished product.

The width of a casing when flattened is calculated using the following formula:

$$\text{Flat width} = \frac{\text{diameter} \times \pi}{2}$$

Woven textile casings are used for products such as high-quality salami and cooked ham. Cotton is frequently used as the basic raw material for the production of textile casings. There are casings on the market which have a layer of colour on the inside and are almost waterproof. These colour-transferring textile casings are filled dry (without being soaked) and the first processing step during thermal treatment of products filled into this type of casing dries the filled meat product (usually a cooked ham product). The

drying process ensures a lasting transfer of colour from the casing on to the surface of the meat product.

### 35.6 Different packaging materials

Packaging of meat products, as well as most other foods, is a huge industry because the packaging has to fulfil criteria such as adequately protecting the food as well as marketing the food at the same time. Packaging has to provide barriers predominantly against microorganisms, O<sub>2</sub>, moisture and light (UV light). All those factors, if present, contribute to reducing the quality of meat and meat products in one form or another. Packaging materials utilized also must be resistant against mechanical forces and must not, if in direct contact with the meat product, present a danger to human health by containing harmful substances that might migrate into the food.

Natural casings can also be considered as a form of packaging even though products filled in these types of casing are most often covered by secondary packaging in order to avoid fully the penetration of O<sub>2</sub> (air) and/or moisture into and out of the product. Natural casings normally display a thickness of between 700–1300 µm, which equals 0.7–1.3 mm as 1 µm is 1/1000 mm or 10<sup>-6</sup> m. Natural casings such as hog or sheep casings exhibit a permeability to O<sub>2</sub> of between 450 and 700 cm<sup>3</sup>/m<sup>2</sup> day bar. Collagen casings have an O<sub>2</sub> permeability of 70–100 cm<sup>3</sup>/m<sup>2</sup> day bar and are around 110–140 µm in thickness. Permeability regarding moisture (water) of natural casings is between 1900 and 2100 g/m<sup>2</sup> day, with collagen casings having a water permeability of around 800 g/m<sup>2</sup> day.

Other casings utilized are a type of packaging by themselves and waterproof as well as fibrous casings (such as those used in salami) are often the final form of packaging. The permeability of fibrous casings to O<sub>2</sub> lies between 180 and 250 cm<sup>3</sup>/m<sup>2</sup> day bar whilst the permeability to water is between 2100 and 2500 g/m<sup>2</sup> day. Products within permeable casings such as fibrous casings are commonly vacuum packed to exclude O<sub>2</sub> fully from the product during storage. Fibrous casings are around 90 µm in thickness and vacuum packing of products inhibits growth of aerobic spoilage bacteria such as *Pseudomonas* spp. as well as *Brochothrix thermosphacta*, which degrades protein and fat, thus creating off-flavours. Waterproof casings are commonly the final form of packaging and the thickness of such casings varies between 12 and 50 µm. The permeability of waterproof casings to O<sub>2</sub> is around 0.1–600 cm<sup>3</sup>/m<sup>2</sup> day bar whilst permeability to water is between 0.8 and 40 g/m<sup>2</sup> day.

Vacuum packing of meat products is also often achieved by using thermoforming machines where a tray is formed first out of a more or less solid sheet of plastic and the product to be packed is placed into the formed tray. A vacuum is applied and the top layer, or foil, is applied to cover and seal the tray fully. The thickness of packaging foils varies generally between

15 and 50  $\mu\text{m}$ . Care has to be taken that no meat product is present within the sealing area where the tray and top foil overlap as leakage will occur over time, resulting in a shortened shelf life of the packed product. Generally, the thickness of bags or foils relates to their barrier characteristics, with thicker bags or foils being of higher cost than bags made from thinner material. Quite frequently, problems regarding shelf life of the product occur as a result of changing to another vacuum bag or packaging foil in order to reduce cost with the new materials used being thinner than the standard. The reduced barrier characteristics against  $\text{O}_2$  as well as moisture of less expensive material can mean that the desired shelf life is not achieved. Increased levels of moisture support the growth of countless bacteria and increased levels of  $\text{O}_2$  have a negative impact on cured and cooked meat products, causing quicker fading in colour. In modified-atmosphere-packed raw meat, which has high levels of  $\text{O}_2$  to maintain oxymyoglobin for a prolonged period of time, changing to a less expensive (and most likely thinner) foil can result in increased levels of unwanted metmyoglobin, which is brown–grey in colour. This is because increased levels of  $\text{O}_2$  penetrate through the thinner foil out of the packaging. Increased levels of moisture within products leads to a decrease in flavour intensity because countless aroma components within meat products are water soluble. Quite commonly, a retention sample of the packaging foil offered and trialled in the first place is kept in case problems start to occur later as the producer of packaging material might have reduced the thickness of the packaging foil over time.

## **Part III**

### **Quality and safety issues**



## 36

# Sensory evaluation of meat products

Sensory evaluation plays a major role not only in the quality control of manufactured products but also in the development of new products. To perform sensory evaluations, the opinion of people with different levels of training and experience is sought. One level of evaluators are untrained people, such as customers in a supermarket, who are given samples of food and are asked either for their 'overall' impression or to describe what they like or dislike about the food that they are tasting. Another type of evaluator are people who have had some specific training in sensorial evaluation of food. Finally, there are professional evaluators who are highly trained specialists, who over time quite often develop an exceptional knowledge of products in terms of their desired texture, consistency and visual appearance as well as flavour and taste. Several excellent books are available on the topic of sensory evaluation and this chapter should be seen only as an introduction. To perform a sensory evaluation correctly requires knowledge of statistical mathematics, and matters such as correlations, levels of reliability and levels of significance have to be taken into account. Therefore, different methods of statistical evaluation will not be explained in detail as this would be far beyond the purpose of this chapter.

### 36.1 Ways of evaluating meat products

Meat products can be analysed regarding their fat, protein and water content or their colour, among other variables, but the results of these analyses give no conclusive indication of the taste, aroma and mouth feel of the product. Salty, sour, sweet, bitter and umami (MSG) are the primary taste sensations

and taste is the sensation experienced when taste buds on the surface of the tongue absorb dissolved molecules or ions. The term 'flavour' is often misinterpreted as referring simply to the taste and aroma of food. Flavour, however, is better defined as the combined sensation arising from taste, aroma, texture and temperature of the food evaluated. Flavour can be divided into initial, main and after flavours. Volatile compounds, substances which are released from food by chewing or by the warmth in the mouth and then evaporate into the nose where the sensation is recognized, contribute to the flavour of food. The aroma of food is experienced owing to air flowing through the nose (mucous membranes). Aroma is any property detected by the olfactory system that is pleasant.

Many different methods can be used to evaluate the sensory quality of meat products. A dual test is a method in which two different samples are given to evaluators and they are asked to describe the differences between the samples. In a ranking test, on the other hand, evaluators are given several samples of a product and are asked to assess a particular parameter, e.g. flavour intensity, and to rank the samples accordingly. To perform a ranking test successfully, the only difference between the samples must be variations in the parameter being tested. To test the intensity of onion in a sausage, for example, using this method, the levels of onion in each sample can vary, but the meat and fat materials used, amount of water added, etc., must remain the same.

A sensory evaluation can also be carried out simply by asking testers to describe a sample. Following this method, the evaluator describes a product as regards a given parameter, such as consistency or flavour, or describes the product in general. Using this system, the preferred product can be found without comparing products directly with each other.

In a profile analysis, another method of sensory evaluation, the tester describes different characteristics present in a product in terms of their intensity. In a sensitivity test, on the other hand, the aim is to determine the inclusion level at which 50% or more of the evaluators respond to a certain parameter in a product. For example, a sensitivity test could be used to determine the influence of garlic in a cooked sausage. Following this method, the level of garlic at which 50% or more of the testers start to detect garlic in the sausage would be determined.

## **36.2 Triangular tests and competition evaluations**

In a triangular test, evaluators receive three samples on a plate. Two samples out of the three are the same and one is different. The evaluators are asked to determine which is the single (odd) sample, what the characteristics of the single sample are compared with those of the double sample and which product on the plate (either the double or the single sample) they prefer. Triangular tests (as well as most other sensorial tests) take place in darkened

or poorly lit rooms. This is to avoid recognition of differences between the samples being aided by detection of variation in colour, which indicate that the samples are from different products.

In a triangular test, evaluators are asked to pick the single sample and the results are evaluated by using statistical mathematics and analysing correlations. These evaluations result in different levels of significance and three levels of significance, or  $\alpha$  values, are commonly used. For example, if eight people evaluate a product, a probability level of 95% is obtained if six out of the eight people correctly identify the single sample. This result, at the same time, equals a significance level of 5%, or an  $\alpha$  value of 0.05, meaning that the probability that the result obtained is true is 95%. If seven out of the eight evaluators correctly identify the single sample, the level of significance is 1% resulting in a probability level of 99%, or an  $\alpha$  value of 0.01. If all eight evaluators correctly identify the single sample, the probability level is 99.9% resulting in a level of significance of 0.1%, or an  $\alpha$  value of 0.001. Tables are available which show the level of significance based on different numbers of evaluators. Seven evaluators is the minimum number possible to obtain levels of significance between 5% and 0.1%, equalling  $\alpha$  values between 0.05 and 0.001.  $\alpha$  is a numerical coefficient, or index, of reliability ranging from 0 to 1, which is named after Professor L.J. Cronbach (1916–2001). Cronbach's  $\alpha$  values are a measure of squared correlation between true scores and observed scores.

Most triangular tests carried out in companies follow the method of picking the single or odd sample as described above. However, the test is also sometimes turned around and evaluators are asked to pick the double sample. The results obtained are then statistically evaluated in the same way by determining levels of significance and so forth.

A triangular test is also frequently used to compare two products, which have been made in almost exactly the same way except for specifications relating to one parameter. The evaluators are asked to pick the single sample which is different in one respect from the others as well as to compare the characteristics of the single sample with those of the double sample regarding the point of difference. Evaluators are also asked which sample, double or single, is preferred. They are only asked to describe the single sample in more detail if the initial evaluation resulted in a probability level of 95%, meaning that at least six out of eight evaluators correctly identified the single sample. Only the results of those evaluators who correctly identified the single sample against the double sample are used.

It is important that only one parameter is varied; otherwise it is hard to tell which parameter causes the changes in the product. When less than 95% of all testers identified the single sample correctly, then, from a sensorial point of view, all three samples are regarded as being the same, or the difference between the samples as being insignificant, because an insufficient number of people correctly identified the differences between them. When more than 95% of evaluators correctly identify the single sample as being different

from the double sample, then it is important to test the product further to describe it better from a sensorial point of view and to determine its points of difference from the double sample.

When comparing or trying to match a competitor product using the triangular test, most research and development departments work with a probability level of 95% or a significance level of 5%, which is an  $\alpha$  value of 0.05. Working with a probability level of 95% or less means that, for example, only six or fewer people out of eight correctly identified the single sample against the double sample. If the probability level is less than 95%, this is taken to mean that no significant difference can be seen between the original (double sample) and the matching product (single sample) as an insufficient number of testers correctly identified the single sample against the double sample. If the level of probability is above 95% and more than six people out of eight correctly identified the difference between the single sample and double sample, then more fine-tuning work has to be carried out on the matching product. Possible differences between the original and the matching product with regard to parameters such as flavour, taste or texture have to be reduced further.

When conducting sensorial evaluations, it is important that every opinion or comment made is given equal importance. No tester in such evaluations is ever right or wrong and the opinion of one individual should never be given more credence than that of another.

Competitions in which sausages or other meat products are judged in Europe as well as in other parts of the world use a standard evaluation form. Each product is evaluated with regard to its appearance, consistency, flavour, taste and colour, and points are awarded for each parameter. On the same sheets, shortcomings such as 'too salty' are noted and points are lost as a result. At the end, all the points attained are added up and gold, silver and bronze medals are awarded on the basis of the number of points scored. These evaluations are performed by exceptionally well-trained people, and reliable as well as meaningful results are obtained. Improvements to the recipe or manufacturing process can then be made afterwards by the manufacturer, based on the list of shortcomings and the points scored in the evaluation.

## 37

# **The hazard analysis critical control point (HACCP) in meat-processing companies**

Countless specialized books are available today describing the HACCP in meat-processing companies at various levels of detail. The purpose of this chapter is simply to outline the principles of the HACCP. The principles of the HACCP were first followed in chemical companies in the USA and also in facilities producing nuclear energy. NASA in the USA first introduced an HACCP system for the production of food. It became evident to those in charge of space programmes that the food consumed by astronauts must be safe from a microbiological point of view so that the astronauts would not have to deal with food poisoning or food spoilage whilst in space and therefore the HACCP system for food was created. Since around 1990, the EU has also recognized the HACCP as a method of documenting the production of food and controlling its production.

A hazard in an HACCP plan for a food processor is anything associated with food that has the potential to cause harm to the product and subsequently to the consumer. Food safety is the main concern in food manufacturing nowadays and therefore the HACCP is especially important. The number of food-processing companies is decreasing but, at the same time, larger and larger quantities of food are manufactured to satisfy an increasing population. Therefore, greater volumes of food are being produced by a smaller number of manufacturers and the potential consequences if unsafe foods are produced are more serious.

### **37.1 Hazard analysis critical control point in the supply chain**

As food safety is so important nowadays, the HACCP does not focus on controlling the quality of the finished product; it focuses rather on identifying, analysing and controlling critical points within the manufacturing process in order to produce safe food. The consumer demands food that is guaranteed to be safe, rather than food that is most likely to be safe or food that it is usually safe. Therefore following an HACCP plan is beneficial. The purpose of having an HACCP plan in a meat-processing company is to control the processes involved in manufacturing meat products and to eliminate or reduce risks to the lowest possible level. As such, an HACCP system focuses on the entire manufacturing process, rather than just the end product. Nowadays, it is accepted as standard that a meat-processing company must have an HACCP in place to be able to supply a supermarket chain. For a supermarket to purchase a meat product, every item supplied must be fully traceable in case anything is wrong with one of them.

In an HACCP system, manufacturers make use of approved raw materials (e.g. meat, additives and packaging materials) from approved suppliers and all raw materials used during the production of a product are fully documented by recording batch numbers and so forth. Approved suppliers are usually audited annually and they themselves must follow their own internal HACCP system. Storage and transport of the finished product is also part of the HACCP plan and the HACCP plan from a manufacturer's point of view continues until the product reaches the shelves in the supermarket. As an extension of that, supermarkets also have their own HACCP plan in place.

Within an HACCP plan a distinction is made between a critical control point (CCP) and a critical point (CP). A CCP is a point within the process at which food safety is under threat if the point is not checked and controlled. A threat can be physical (metal in food), chemical (traces of cleaning detergent) or microbiological (presence of excess numbers of *Salmonella* spp.). On the other hand, a critical point is a check point within the process at which food quality is under threat if procedures are not followed properly. The smoke colour on frankfurters, for example, which can be too weak if the smoke generator does not function properly, might be controlled by a check point.

When implementing an HACCP, the plan should be kept as simple as possible. The larger the number of CCPs and critical point implemented, the greater is the task of monitoring. An increased number of checks immediately results in increased levels of documentation. Therefore, a happy medium has to be reached at which food safety is still guaranteed, but the burden of monitoring is not too great.

Before the seven steps of an HACCP plan can be implemented, the following tasks are carried out.

- 1 An HACCP team is created. Members of this team must collectively demonstrate sufficient product and process knowledge to answer all possible questions or to solve all possible problems associated with a product or process.
- 2 Every product has to be described in terms of its composition (types and quantities of meat, fat, additives used, etc.), manufacturing process, packaging, shelf life, storage conditions and distribution. Products made in the same way up to a certain point in the manufacturing process can be grouped as a category. For example, if a processor produces several different types of finely emulsified sausage such as frankfurters and the cutting processes are the same in the manufacture of all the sausages, the cutting process can be described once and will be valid for all different types of frankfurter.
- 3 The intended use of the product and how it is to be consumed, i.e. whether it can be eaten without further heat treatment, must be described.
- 4 A flow chart must be drawn for the manufacture of each product or product group.
- 5 Tests should be carried out to check that the process flow chart can be implemented in the factory. If this is not possible, the flow chart must be corrected until it can be followed by the company.

## **37.2 Key elements in hazard analysis critical control point systems**

There are seven key elements in the HACCP concept.

- 1 *Analysis and identification of the hazards.* This analysis of the hazards within the manufacturing process of a product is product and process specific. Hazards can be chemical (e.g. traces of cleaning detergent on the surface of a table), physical (e.g. a piece of metal or glass in a product) or biological (e.g. presence of a pathogen).
- 2 *Identification of CCPs.* CCPs are the stages within a product's manufacturing process at which corrective action must be taken if necessary to guarantee the safety of the product. A stage can sometimes be described in more detail either as a CCP1, a point at which a possible risk is totally controlled or eliminated, or a CCP2, a point at which a risk is reduced to the lowest possible level but not eliminated.
- 3 *Establishment of criteria or limits.* These criteria, which ensure that a process is in control, include parameters such as temperature, cooking time,  $A_w$  or pH. If these criteria are observed, possible physical, chemical or microbiological threats are reduced to an acceptable level or totally eliminated.
- 4 *Establishment of a monitoring process.* The monitoring process is utilized to check that the established criteria are followed and fulfilled. Monitoring

is the key step in an HACCP plan because it is at this stage that alarms can be raised as soon as the established criteria are not followed or fulfilled. Put simply, by monitoring it is determined whether or not a CCP is in fact under control.

- 5 *Establishment of a corrective action plan.* Establishing a corrective action plan in advance to rectify a situation as soon as monitoring indicates that established criteria are not being followed saves much time and avoids confusion when a process becomes 'out of control' and corrective action is required as everybody involved knows precisely what to do in such situations.
- 6 *Establishment of a verification process.* A verification process is literally a process that controls the CPs. It verifies that the finished product will be safe to be consumed if all implemented steps and CCPs are followed. Verification is the use of methods, procedures and tests in addition to monitoring to determine compliance with the food safety programme. An example of a verification process would be microbiological tests carried out at the end of a product's shelf life to prove that the guaranteed shelf life was obtained. Outside companies commonly inspect manufacturers to ensure that their HACCP plan is followed properly and this is another example of verification.
- 7 *Establishment of record-keeping and documentation procedures.* This is the last step in an HACCP plan. All tests carried out, and checks made, etc., have to be recorded (or ticked off) and the documentation filed away properly.

If an HACCP plan is followed, there are several advantages.

- 1 Everybody, including even the owner of a company, follows the same established rules and guidelines.
- 2 Contrary to common belief, the implementation of an HACCP does not require as large an effort as appears. To a great extent, it only involves recording what is carried out anyway during day-to-day production.
- 3 An HACCP plan forces people to analyse and to think about the current production process and quite a few improvements can be made as a result.
- 4 An increased number of people obtain a thorough understanding of the manufacturing process.
- 5 If a process fails, the method of corrective action to be taken is already agreed upon, saving much time and confusion.
- 6 If a process fails and the right corrective action is taken quickly, money is saved as a result.
- 7 Fewer customer complaints arise; the standardized manufacturing process ensures that a standardized product is produced all the time.
- 8 Standardized manufacturing of products is the basis for an accurate costing of the product produced.
- 9 The fact that an HACCP plan is in place can be used as a marketing tool.

- 10 If products have to be recalled, documentation shows exactly where the finished product is located and therefore the affected batch(es) can be recalled efficiently.
- 11 Hence, if it can be proven that materials such as the packaging used were faulty, claims can be made against the manufacturer of the packaging material.

Specific methods of production such as halal and kosher can also be maintained as part of an HACCP system. Halal products must conform to Islamic dietary laws as written in the Qu'ran and texts. The Hebrew word 'kosher' means 'right'. Kosher food must be selected and prepared in accordance with Jewish dietary and ritual laws.

## 38

# Introduction to the microbiology of meat and meat products

Microbiology, besides being a science in its own right, is commonly called the 'supporting science' of meat technology because many of the reactions and processes that occur within the manufacture of meat and meat-related products are closely related to microbiology. The purpose of this chapter is not to go into every detail of microbiology, but rather to give a broad overview of the subject as it relates to meat and meat products. Microbiology itself has developed into specialized studies such as bacteriology, mycology, phycology, virology and protozoology.

It is widely believed that the presence of bacteria is always harmful, but this is far from the case. In fact, of all the microorganisms known today, only around 2% are harmful to humans. Even of those 2% of harmful bacteria, healthy human beings, possessing a fully functioning immune system, are able to withstand most of those. On the other hand, humans with a weakened immune system, such as infants, very old people, pregnant woman and others are significantly more susceptible to falling ill from the impact of some of those 2% of bacteria. Those most at risk are known as the YOPIS, which is an abbreviation of the young (infants), the very old, pregnant and immunocompromised segment of the population. 98% of bacteria are 'helpful' towards life overall and life without bacteria just would not be possible. Within meat technology the important and difficult task is to control those few microbes that could do harm to humans if food is contaminated with those spoilage bacteria or pathogens which are able to produce toxins.

The TPC, or the number of colony-forming units per gram, is the number of bacteria present on 1 g or 1 cm<sup>2</sup> of sample. This is measured in aerobic conditions with the microorganisms growing at 30 °C on a selected base, such as agar-agar. Different types of base, which provides the food for the

bacteria, are used because the different results in different bases helps to determine the type of microorganism present within the TPC. The TPC is normally used to count the number of microorganisms on the surface areas of meat and meat products whilst the cfu number is used to determine the number of microorganisms present per gram (weight) of food and is expressed in units of cfu/g. Numbers are expressed to the power of 10, such as  $10^3$  for 1000,  $5 \times 10^4$  for 50 000 or  $6.5 \times 10^5$  for 650 000.

### 38.1 Classification and naming of microorganisms

Classification is the process in which individual species are arranged in groups within a hierarchical system following the sequence: kingdom → division or phylum → class → order → family → genus or genera → species. Gram staining is commonly used to aid classification and differentiation. Cell shape and the measurement of oxygen requirements are also used in classification but are of more use in differentiating microorganisms.

Naming of specific organisms is based on a system firstly developed by Carl von Linne following a binominal system of nomenclature and focus is placed on the family, genus and species. As an example, *Staphylococcus aureus* is an important bacterium in meat and meat products and is classified as follows:

family: Micrococcaceae

genus: *Staphylococcus*

species: *aureus*

The first letter of the genus is always written with a capital letter whilst the name for the species starts with a small letter (lower case). Some species even have subspecies such as *Lactococcus lactis* (subsp.) *lactis* or *Campylobacter jejuni* subsp. *doylei*.

The following are examples of abbreviations for common bacteria:

<i>Escherichia coli</i>	<i>E. coli</i>
<i>Staphylococcus aureus</i>	<i>Staph. aureus</i>
<i>Bacillus cereus</i>	<i>B. cereus</i>
<i>Clostridium botulinum</i>	<i>Cl. botulinum</i>
<i>Lactobacillus plantarum</i>	<i>Lb. plantarum</i>
<i>Streptococcus salivarius</i>	<i>Strep. salivarius</i>
<i>Pseudomonas fluorescens</i>	<i>Ps. fluorescens</i>
<i>Salmonella typhi</i>	<i>S. typhi</i>
<i>Shigella sonnei</i>	<i>Sh. sonnei</i>

Naming of bacteria can be confusing at times as names occasionally change. As an example, *Shewanella putrefaciens* was formerly *Pseudomonas putrefaciens* and later called *Alteromonas putrefaciens*. *Streptococcus lactis*

is now *Lactococcus lactis*. Bacteria can be heterotrophic or autotrophic. Heterotrophic bacteria require organic material such as glucose for living whilst autotrophic bacteria generate energy required for living by themselves.

The presence, or absence, of flagella (see Chapter 39, Section 39.1) is also used as a way to classify and identify bacteria. For example, members of the families Enterobacteriaceae as well as Bacillaceae exhibit peritrichous flagella whilst members of the genus *Pseudomonas* display polar flagella.

## 38.2 Endotoxins versus exotoxins

Meat and meat products can be spoiled as a result of large numbers of spoilage bacteria such as *Pseudomonas* spp. or *Brochothrix thermosphacta* which cause the formation of slime, gas, discolouration and an off-flavour but no toxin. Pathogens are able to produce one of two different types of toxin which can be harmful to humans. Food poisoning can occur in the form of a food infection on one hand or intoxication on the other. In both cases, growth in the number of bacteria has to take place, either within the human being (infection) or within food itself (intoxication) to generate sufficient toxin to cause illness. Gram-negative bacteria generally produce endotoxins which are lipopolysaccharides and which cause food infections. Pathogens consumed place themselves mainly in the gastrointestinal system and growth takes place there. The lipid fraction (lipid A) of the lipopolysaccharide represents the actual toxin. The toxin, which was originally part of the outer membrane of the cell wall, is released through lysis of the cells. Once a sufficient number of pathogens are present, illness is the result. During the growth period of the cell the toxin produced remains within the bacteria cells close to the surface until it is released through lysis of the cell. Because the pathogens have to multiply first in order to cause sickness, the incubation period before sickness occurs is fairly long and can vary from 8 to 16 h from the food infection. The main symptoms caused by food infection are diarrhoea, stomach ache and occasional vomiting. The majority of endotoxins are heat stable and endotoxins are generally less potent than exotoxins.

Exotoxins are primarily proteins and enzymes and are produced inside the bacteria through metabolic activity. They cause intoxication in meat and meat products. Exotoxins are primarily produced by Gram-positive bacteria and are not part of the cell wall but are proteins synthesized as a result of metabolic activity. They are released into the environment surrounding the cell such as meat or meat products. Exotoxins are soluble in body fluids and can therefore be easily transported all over the body, partly destroying the host cell by interfering with its metabolism. Three different types of toxin belong to the group of exotoxins: cytotoxins, enterotoxins and neurotoxins. Neurotoxins interfere with the nervous system whilst enterotoxins affect the lining of the intestines and cytotoxins even kill the host cells. The term 'enterotoxin' comes from the Greek word 'enteron' meaning intestine and

'toxicum', which means toxin; such toxins are primarily active in the intestine system of humans. Exotoxins are produced by bacteria while they grow in numbers, are released into the food and cause food intoxication. Contaminated, or poisoned, food has to be consumed in order to fall sick. Intoxication is also occasionally known as food poisoning as the poison is already present in food consumed; however, both infection and intoxication ultimately result in food poisoning. As the toxins are already present in consumed food, the incubation time for intoxication is short and sickness can be seen around 3–4 h after the contaminated food was eaten. Vomiting and diarrhoea, as well as headache and stomach ache, are the main symptoms. The severity of sickness depends on the type and amount of toxins consumed and in some cases can result in death. Most exotoxins are heat labile. Exotoxin-producing species such as *Staph. aureus*, *Clostridium botulinum* and *Bacillus cereus* are the most important representatives in meat and meat products. Table 38.1 lists bacteria causing either food infection or food intoxication.

With some bacteria, significant growth in numbers is not required to cause illness as a low number is sufficient. Bacteria such as *Salmonella typhi*, *Vibrio cholerae* and enterohaemorrhagic *Escherichia coli* belong to this group in that consumption of numbers as low as, or even below, 100 can cause illness.

### 38.3 Temperature tolerance of microorganisms

Bacteria and fungi are classified into five groups as regards the preferred temperature range for growth. Table 38.2 demonstrates the preferred growth temperature for microorganisms. The rate, or speed, of reproduction drops sharply above and below the optimum as the temperature has a significant impact on metabolic activities of bacteria. Very few bacteria exhibit growth below  $-6\text{ }^{\circ}\text{C}$  and even fewer below  $-10\text{ }^{\circ}\text{C}$ . However, yeast (fungi) such as *Debaryomyces* spp. can grow at temperatures as low as  $-13\text{ }^{\circ}\text{C}$ . Mesophile bacteria do not grow at chilling temperature between  $-1$  and  $4\text{ }^{\circ}\text{C}$  and Gram-positive bacteria are more resistant to cold than are Gram-negative bacteria. Parameters such as the age of the cell itself, the composition of food (pH

**Table 38.1** Bacteria causing food-based infection or intoxication

Food infection	Food intoxication
<i>Campylobacter jejuni</i>	<i>Bacillus cereus</i>
<i>Escherichia coli</i>	<i>Clostridium botulinum</i>
<i>Listeria monocytogenes</i>	<i>Staphylococcus aureus</i>
<i>Salmonella typhimurium</i>	
<i>Yersinia enterocolitica</i>	
<i>Shigella</i>	
<i>Aeromonas hydrophila</i>	

**Table 38.2** Preferred growth temperatures for microorganisms

	Minimum temperature (°C)	Optimum temperature (°C)	Maximum temperature (°C)
Psychrophile	-12	5–15	20
Psychrotroph	-8	20–25	35
Mesophile	5	30–45	50
Thermophile	35	45–60	70
Extreme thermophile	70	85–90	100

value) and treatment before freezing (blanching) have an impact on the survival of bacteria at freezing temperatures. Also, the thawing speed of meat and the storage time under frozen conditions have an impact on growth. Once again, Gram-positive bacteria demonstrate greater resistance towards freezing temperatures than Gram-negative bacteria. Despite the fact that a small number of microorganisms are killed during freezing and during storage of meat under frozen conditions, freezing should never be regarded as a means of reducing the bacteria count in meat. Table 38.3 shows the minimum growth temperature required for major spoilage bacteria, pathogens and fungi. Table 38.4 lists the optimum and maximum temperatures in °C for spoilage bacteria and pathogens to grow.

The resistance of different organisms towards the impact of heat differs greatly. Generally, aerobic bacteria are less resistant to heat than are anaerobic bacteria. Gram-positive bacteria are more resistant to the impact of heat than the thinner walled Gram-negative bacteria (Table 38.5).

### 38.4 Oxygen tolerance of microorganisms

Another point of distinction between microorganisms is their tolerance of, or need for, oxygen (O<sub>2</sub>). Obligate aerobic bacteria require oxygen in order to live and to grow. Bacteria such as *Pseudomonas* spp. and *Aeromonas* spp. belong to this group as well as fungi and the absence of O<sub>2</sub> leads to the death of those organisms. Facultative anaerobic bacteria, such as lactic acid bacteria, can use O<sub>2</sub> if present but can live without oxygen as well. However, growth of lactic acid bacteria is enhanced by the presence of carbon dioxide (CO<sub>2</sub>). Obligate anaerobic bacteria cannot tolerate O<sub>2</sub> which acts as a poison towards them. The most well-known representative in the group of obligate anaerobic bacteria is *Cl. botulinum*.

Microaerophile organisms thrive in an atmosphere containing reduced levels, around 6% and below, of O<sub>2</sub>. Growth is stimulated by the presence of CO<sub>2</sub> and a level of 10–12% is seen as the optimum. The presence of O<sub>2</sub> sometimes affects the required water levels of a bacterium. For example,

**Table 38.3** Minimum growth temperature for major spoilage bacteria, pathogens and fungi

Genus or species	Minimum growth temperature (°C)
<i>Campylobacter jejuni</i>	30
<i>Clostridium perfringens</i>	17
<i>Escherichia coli</i> , <i>Staphylococcus aureus</i> , <i>Proteus</i> , <i>Micrococcus</i>	7
<i>Salmonella</i> , <i>Citrobacter</i>	5
<i>Clostridium botulinum</i> type E	3.5
<i>Lactobacillus</i> , <i>Listeria monocytogenes</i> , <i>Aeromonas</i>	0
<i>Yersinia enterocolitica</i>	-1
<i>Pseudomonas fluorescens</i>	-4
Selected yeast and mould	-5
<i>Pseudomonas fragii</i>	-6
Yeast, <i>Vibrio parahaemolyticus</i>	-10
Moulds such as <i>Fusarium</i>	-18

**Table 38.4** Optimum and maximum growth temperatures for spoilage bacteria and pathogens

Microorganism	Optimum temperature (°C)	Maximum temperature (°C)
<i>Staphylococcus aureus</i>	37	45
<i>Bacillus cereus</i>	32	45
<i>Clostridium botulinum</i> types A/B	38	50
<i>Clostridium perfringens</i>	40	50
<i>Salmonella</i> spp.	37	45
<i>Escherichia coli</i>	37	45
<i>Pseudomonas fragii</i>	22	37
<i>Pseudomonas fluorescens</i>	25	38
<i>Campylobacter jejuni</i>	40	45
<i>Aeromonas</i>	26	40

**Table 38.5** Degrees of heat resistance shown by bacteria

Degree of heat resistance	Mould and yeast
Not or very slightly heat resistant	Mould and yeast
Slightly heat resistant	Gram-negative bacteria (thin cell wall)
Heat resistant	Gram-positive bacteria (thicker cell wall)
Very heat resistant	Spore-forming bacteria from the genera <i>Bacillus</i> and <i>Clostridium</i>
Extremely heat resistant	Thermophilic spore-forming bacteria from the genera <i>Bacillus</i> and <i>Clostridium</i>

*Staph. aureus* shows growth at an  $A_w$  of 0.90 under anaerobic conditions. Table 38.6 shows the different  $O_2$  requirements of various organisms.

### 38.5 Optimal pH value in meat for bacterial growth

Generally, a reduced pH value suppresses growth of bacteria while strong growth is seen in a pH range between 6.2 and 6.4 in different types of meat such as beef, chicken and pork. At such high pH levels, the natural acidification which took place in muscle tissue during rigor mortis, lowering the pH value to around 5.3, is no longer an effective hurdle especially as the pH values rise after rigor mortis owing to the metabolic activity of protease such as cathepsins, thus supporting bacterial growth. In fish, optimal growth is seen commonly at pH values between 6.1 and 6.7 except for tuna, where growth takes place at its fastest rate by a pH value between 5.4 and 6.1. Overall, bacteria prefer a pH value around neutral, between 6.6 and 7.2, for growth but such levels in pH value never occur in meat as meat is spoiled at a pH value of around 6.4 owing to the formation of slime, discolouration and off-flavours. Most types of mould prefer a pH value around 4.5 for optimal growth. Table 38.7 shows the minimum pH value required for growth of different organisms.

### 38.6 Minimum $A_w$ needed for bacterial growth

Most common pathogens require an  $A_w$  above 0.95 in order to grow and/or to produce toxins. However, other potentially dangerous bacteria such as *Staph. aureus* and *Listeria monocytogenes* demonstrate growth at significantly lower  $A_w$ . Table 38.8 shows the level of  $A_w$  inhibiting growth of certain microorganisms.

**Table 38.6** Different  $O_2$  requirements for various microorganisms

Microorganism	$O_2$ requirement
<i>Bacillus cereus</i>	Facultative anaerobic
<i>Yersinia enterocolitica</i>	Facultative anaerobic
<i>Salmonella</i> spp.	Facultative anaerobic
<i>Staphylococcus aureus</i>	Facultative anaerobic
<i>Escherichia coli</i>	Facultative anaerobic
<i>Listeria monocytogenes</i>	Facultative anaerobic
<i>Clostridium botulinum</i>	Obligate anaerobic
<i>Clostridium perfringens</i>	Obligate anaerobic
<i>Pseudomonas</i> spp.	Aerobic
Mycotoxigenic mould	Obligate aerobic
<i>Campylobacter</i> spp.	Microaerophile

**Table 38.7** Minimum pH required for growth of different microorganisms

Microorganism	pH value
<i>Clostridium botulinum</i>	> 4.7
<i>Clostridium perfringens</i>	> 4.9
<i>Bacillus</i> spp.	> 4.5
<i>Lactobacillus</i> spp.	> 3.2
<i>Salmonella</i> spp.	> 4.4
<i>Pseudomonas</i> spp.	> 4.7
<i>Staphylococcus aureus</i>	> 4.6
<i>Listeria monocytogenes</i>	> 5.0
<i>Klebsiella</i> spp.	> 5.1
<i>Aeromonas</i> spp.	> 5.3
<i>Leuconostoc</i> spp.	> 4.8
<i>Brochothrix thermosphacta</i>	> 5.0
<i>Escherichia coli</i> O157:H7	> 4.0
<i>Yersinia enterocolitica</i>	> 4.4

**Table 38.8** Level of  $A_w$  inhibiting growth of certain microorganisms

Genus or species	Minimum $A_w$
<i>Pseudomonas</i> , <i>Campylobacter jejuni</i> , <i>Clostridium perfringens</i>	0.97
<i>Bacillus cereus</i>	0.96
Enterobacteriaceae ( <i>Salmonella</i> ssp. and <i>Escherichia coli</i> ), <i>Clostridium botulinum</i> types A and B	0.95
<i>Brochothrix thermosphacta</i>	0.94
<i>Lactobacillus</i> spp., <i>Pediococcus</i> spp.	0.93
<i>Listeria monocytogenes</i> , <i>Yersinia enterocolitica</i>	0.92
<i>Streptococcus</i> spp.	0.91
<i>Saccharomyces cerevisiae</i> , <i>Staphylococcus aureus</i> (anaerobic), <i>Micrococcus</i> spp.	0.90
Most species of yeast	0.88
<i>Staphylococcus aureus</i> (aerobic)	0.86
Most species of mould	0.80
<i>Aspergillus flavus</i>	0.78
<i>Aspergillus niger</i>	0.76
Xerophilic (dry-loving) moulds	0.62

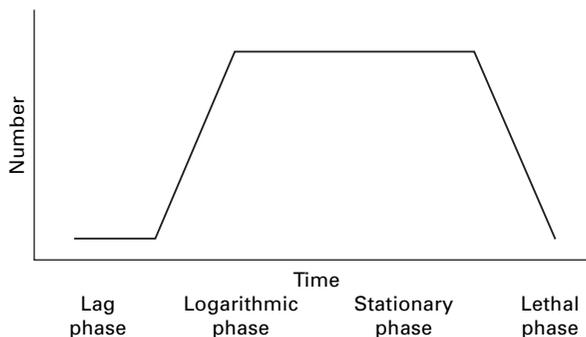
In quite a few pathogens, formation of the toxins does not take place at the same level of  $A_w$  or pH as is required for growth; this is because the bacterium has to adjust itself fully to its surroundings before production of toxins commences.

### 38.7 Growth curve of bacteria

The growth of bacteria follows a certain pattern which can be divided into four phases.

- 1 *Lag phase.* This is the period of time where the bacteria have to adjust themselves to new living circumstances such as the availability of food and water, the pH level and the temperature that the meat is stored under. The number of cells remains virtually unchanged during this period of time and the lag phase can last from 1 h up to several days. Extending the lag phase is the primary aim to obtain a prolonged shelf life of meat or a meat product.
- 2 *Logarithmic phase.* Once adjusted to the new living circumstances, the bacteria start to reproduce and reproduction proceeds logarithmically. The number of cells increases dramatically during the logarithmic phase.
- 3 *Stationary phase.* During reproduction in this phase, toxic metabolic by-products are given off which eventually kill living cells. As new cells are still being produced during this stage the total number of living cells remains constant. As a result, growth reaches equilibrium point.
- 4 *Mortality or lethal phase.* In this final stage, the huge amount of toxic by-products kills more cells than are reproduced and the number of living cells overall decreases rapidly to a point where the culture is almost extinct. Death can be caused by the depletion of cellular energy, accumulation of toxic metabolic by-products or changes in the pH value of the surroundings of the bacteria.

Figure 38.1 shows a typical growth curve of bacteria. The shape of this curve and the periods of time involved for each phase depend on parameters such as the availability of food and water, the variations in temperature and the presence or lack of oxygen to name just a few.



**Fig. 38.1** Typical growth pattern for bacteria.

### **38.8 Gram-positive and Gram-negative bacteria**

For classification purposes, bacteria can be stained (coloured) and Gram staining, named after the Danish microbiologist Hans Christian Gram (1853–1938), is used. Using the Gram method, bacteria are divided into Gram-positive and Gram-negative bacteria. The bacteria are coloured first with the aniline dye crystal violet. Once coloured, bacteria are washed with 95% concentrated ethanol and the counter-stain safranin, or occasionally fuchsin, is applied afterwards, which is a basic red dye. With this treatment, during the washing with ethanol, Gram-positive bacteria retain the crystal (blue–violet colour originally introduced. The cell wall thickness of Gram-positive bacteria is around twice that of Gram-negative bacteria and contains around 60–70% of the glycol protein, or peptidoglycan, murein. The murein net surrounding Gram-positive bacteria consists of around 40 layers and the cell wall contains around 2% lipids as well. The layers of murein add strength to the cell, maintain the cell's shape and counteract osmotic pressure. Those layers of murein within the cell wall hold the crystal violet well which is not washed out by ethanol.

On the other hand, Gram-negative bacteria are completely decolourized during washing with ethanol and are colourless once washed, taking up the red counter-stain safranin which explains why Gram-negative bacteria finally appear red. In fact, the counter-stain is taken up by both Gram-positive and Gram-negative but does not change the colour in the Gram-positive bacteria where the violet colour remains the dominant colour. Gram-negative bacteria are surrounded in most cases by a single-layered, and sometimes a double-layered, net of murein, which accounts for only around 10% of the entire cell wall. The lipid content of the cell wall of Gram-negative bacteria is around 20%. As a rule of thumb, Gram-negative bacteria are more harmful to humans, causing the majority of food poisonings as they commonly contain lipopolysaccharide (endotoxins) in their outer cell membrane. Table 38.9 shows the most important bacteria (Gram positive or Gram negative) in meat and meat products. Table 38.10 shows the minimum levels of common pathogens needed to cause illness.

### **38.9 Microbiological spoilage of meat and meat products**

The growth of bacteria and therefore the shelf life of fresh meat are to a large extent determined by the combination of the initial bacteria count in conjunction with the storage temperature applied by following a logarithmic curve. This means extending the lag phase as long as possible (see Section 38.7) by creating a non-hostile environment for bacteria. Most spoilage bacteria found in fresh meat are Gram positive and aerobic whilst the desired bacterial flora on fresh meat are generally facultative anaerobic and Gram negative. Those are only present initially on meat in small numbers. The bacterial flora on

**Table 38.9** Major Gram-positive and Gram-negative bacteria in meat

Gram-positive genera	Gram-negative genera
<i>Bacillus</i>	<i>Pseudomonas</i>
<i>Clostridium</i>	<i>Escherichia</i>
<i>Micrococcus</i>	<i>Salmonella</i>
<i>Staphylococcus</i>	<i>Proteus</i>
<i>Streptococcus</i>	<i>Enterobacter</i>
<i>Pediococcus</i>	<i>Campylobacter</i>
<i>Lactobacillus</i>	<i>Yersinia</i>
<i>Leuconostoc</i>	<i>Aeromonas</i>
<i>Listeria</i>	<i>Citrobacter</i>
<i>Brochothrix</i>	<i>Vibrio</i>
<i>Enterococcus</i>	<i>Shigella</i>

**Table 38.10** Minimum levels of key pathogens required to cause illness

Microorganism	Number consumed
<i>Salmonella typhi</i>	< 10 <sup>2</sup> *
<i>Salmonella</i> spp.	> 10 <sup>5</sup> *
<i>Campylobacter</i> spp.	> 4 × 10 <sup>2</sup> *
<i>Listeria monocytogenes</i>	> 10 <sup>3</sup> †
<i>Bacillus cereus</i>	> 10 <sup>5</sup> †
<i>Staphylococcus aureus</i>	> 10 <sup>6</sup> †
<i>Clostridium perfringens</i>	> 10 <sup>6</sup> †

\*Total number.

†Consumption per gram of food.

fresh meat contains around 30 different genera and the most common are as follows.

- 1 Gram-positive rods: *Clostridium* spp., *Bacillus* spp., *Brochothrix* spp., *Lactobacillus* spp. and *Listeria* spp.
- 2 Gram-positive cocci: *Pediococcus* spp., *Enterococcus* spp., *Lactococcus* spp., *Micrococcus* spp., and *Staphylococcus* spp.
- 3 Gram-negative cocci and rods: *Aeromonas* spp. *Enterobacter* spp. *Citrobacter* spp. *Escherichia* spp., *Proteus* spp., *Salmonella* spp., *Yersinia* spp., *Pseudomonas* spp., *Shigella* spp. and *Campylobacter* spp.

In most places in the world, the term 'fresh meat' refers to meat that has never been treated in any way, as well as meat that has never been frozen. Fresh meat refers commonly to the non-use of any additive, flavour, colour, etc., and, as soon as any form of treatment is applied to fresh meat, terms such as 'tenderness enhanced' or 'moisture enhanced' (see Chapter 34) are used. The shelf life of fresh meat and meat products is a combination of extrinsic as well as intrinsic factors. The extrinsic factors are the storage temperature, RH in the room and storage time. Intrinsic factors are the initial

bacteria count of the meat, the nutrient content and the pH value of the meat product, the  $A_w$  value, the  $E_h$  value and whether the meat is packed or not. On fresh meat, obtaining a low bacteria count on the carcass meat starts at the abattoir, or even before that. If an animal is treated really badly prior to slaughter, bacteria from the intestines can penetrate through the gut wall into surrounding muscle tissue, contaminating it. Meat which experiences excessive contamination during the slaughtering process, will never exhibit a satisfying shelf life. Enterobacteriaceae are introduced on to meat as a result of poor slaughtering hygiene as well as bacteria such as *Brochothrix thermosphacta*. In most countries in the world, if the intestines are cut open during evisceration and the content of the intestines, or stomach, comes into contact with the surface of the carcass, the affected areas must be cut out rather than washed down with water. Even thorough washing with water just distributes bacteria all over the carcass and the damage done is significantly greater overall than if the affected area is removed. Commonly, decontamination of the surface of carcasses, especially in beef and chicken, is achieved by applying organic acids and solutions of pyrophosphates. Scalding of pigs or defeathering of birds is another very critical step which has to be monitored closely to keep the bacteria count on the surface low. Chilling of birds with water is another possible way to contaminate the chicken carcasses and proper levels of chlorine have to be maintained within the chilling water. Chilling the carcass at a proper speed also plays a vital role. Chilling it too quickly does not cause a microbiological problem, but cold shortening can be obtained. On the other hand, if the carcass is chilled too slowly, bacteria have a perfect breeding ground. On large pieces of muscle from a beef carcass, such as the hind leg, the topside is occasionally partly removed to allow cold air to chill thick parts of muscle more effectively. The air speed in the chiller during storage of meat should be around 0.1–0.3 m/s. Chilling of meat and meat products is the most widely used form of preservation as low temperatures, around 0–4 °C, only permit selective bacteria to survive or to grow. Cold-tolerant bacteria such as *Pseudomonas* spp., *Yersinia* spp., *Listeria* spp., *Brochothrix* spp. and *Aeromonas* spp. can still grow under chilled conditions. Excessive growth of these leads to a slimy surface on meat, undesirable off-flavours and a change in colour. Most of those chiller bacteria are aerobic and require  $O_2$  in order to survive and to grow. Other aerobic spoilage bacteria include *Acinetobacter* spp., *Psychrobacter* spp. and *Moraxella* spp. which are Gram-negative cocci. Storage of meat should take place between –1 and 2 °C as most bacteria contributing to spoilage of meat are inactive or their activity is greatly reduced within this temperature range. The fact is that storage temperatures close to, at or slightly below 0 °C extend shelf life many times in comparison with temperatures in the range 3–4 °C and every single degree Celsius closer to freezing point is beneficial.

Overall hygiene within an abattoir and the meat factory plays another vital role regarding extending shelf life. Hygiene can be divided into the two major areas of factory and personal hygiene. It is not the purpose of this

book to describe in detail which types of precaution have to be in place such as cleaning regimes, steps towards disinfection, swab test for bacteria counts on machines and so forth to ensure a low bacteria count. Simply, a factory must be kept clean and the proper cleaning and disinfection materials have to be applied and utilized in the correct way to achieve this goal. It is also a well-known fact that keeping a factory clean is quite a costly exercise but unfortunately there is no cheap alternative and cutting corners can backfire badly. Personal hygiene complements factory hygiene and, if one of those two is not properly in place, the shelf life of meat and meat products is badly affected.

Maintaining a high level of hygiene in every respect and a low bacteria count, in combination with low storage temperatures, are in effect the two major hurdles against spoilage of fresh meat. In boning rooms, the temperature should be as low as possible and around 10 °C is seen as the absolute maximum as the temperature of meat itself should never exceed 6°C. Most commonly, boning occurs at significantly lower temperatures such as 2–5 °C. The RH in boning rooms should be between 50% and 60% in order to avoid formation of condensation water (see Chapter 4, Section 4.12) on the surface of the meat during boning. Condensation on the surface of the meat results commonly in sliminess very soon after. The air present in boning rooms should also be filtered if possible. No pools of water should remain on the floor after cleaning as such pools are breeding grounds for all types of bacteria such as *L. monocytogenes*. As a general rule, walls and especially floors of boning rooms (as well as processing factories) should be kept dry and cold. Protective clothing such as metal gloves, aprons and cotton gloves worn under the protective gloves present a perfect breeding ground for bacteria. A layer of plastic should be worn between the cotton and metal glove to ensure that the meat is not contaminated if the cotton gloves are worn for a prolonged period of time. Another option is frequently to change the gloves. Membrane-skipping machines, utilized for skinning pieces of meat for retail level, but also for processing afterwards, have to be kept clean. If not cleaned properly, all such machines present a microbiological hazard and the shelf life of meat subsequently treated on the machine is very badly affected.

Generally, off-flavour, which is a result of spoilage in meat, can be observed from a bacteria count of around  $10^7$  per square centimetre or gram but negative changes can be observed much earlier with bacteria counts between  $10^5$  and  $10^6$  per square centimetre or gram of meat or meat product. Psychrotrophic bacteria such as *Ps. fluorescens* and *Ps. fragii* also produce protease and as such, in a late stage, cause spoilage of fresh chilled meat. Proteins are broken down, creating highly alkaline metabolic by-products which result in large amounts of objectionable odours as well as a changed appearance and flavour of the fresh meat. Odours include ammonia, amines, hydrogen sulphide ( $H_2S$ ) and other sulphur-containing compounds such as dimethyl sulphide. *Pseudomonas* spp. firstly use  $O_2$  and glucose from the meat as energy and

once the supply of glucose is exhausted, they start to metabolize proteins as their source of carbon. Hence, *Ps. fluorescens* breaks down sulphur-containing amino acids such as methionine and cysteine. Highly alkaline metabolic by-products cause the pH value in meat to rise above 6.4–6.5 within a relatively short period of time, causing finally spoilage of meat. Some species of heterofermentative *Lactobacillus* also produce H<sub>2</sub>S, causing intense off-flavours. Also, a microbial cell undergoes lysis in its final stage of life and protease changes the texture and flavour of meat overall. Off-flavours can be the result of the activity of *Serratia* spp. or *Hafnia* spp. at a pH value above 5.9, or the formation of H<sub>2</sub>S through proteolysis. Slime is formed on the surface of meat if numbers of *Pseudomonas* spp. or members of the Enterobacteriaceae and Micrococci families reach 10<sup>7</sup>–10<sup>8</sup> per square centimetre.

*L. monocytogenes* is regularly present on fresh meat as well as *Staph. aureus*. Growth of *L. monocytogenes* on fresh meat is normally insignificant as the competitive flora, here predominantly *Lactobacillus* spp., does not allow *L. monocytogenes* to grow.

Contamination of meat and meat products with *Staph. aureus* is commonly related to coughing or sneezing in the presence of meat as *Staph. aureus* is present in large numbers in the nose and mouth area in humans. Hence, people working with meat who have infected or open wounds frequently cause contamination with *Staph. aureus* and wounds containing pus are a perfect breeding ground for *Staph. aureus*.

*C. jejuni* is often related to chicken and red meat and the consumption of just a few of those bacteria leads to sickness.

Verocytotoxin-producing *E. coli* are associated with all types of meat.

The shelf life of minced meat could be extended by adding food acids, such as lactic acid or citric acid, to reach a pH value of around 5.2–5.3 but this is not acceptable from a sensorial point of view. In addition, even at a reduced pH value of 5.4 but a temperature between 8 and 10 °C, *Salmonella* spp. readily multiply. Minced meat is to be produced from good quality meat, displaying a low bacteria count, and trimmings of meat displaying a high microcount should not be turned into mince. Minced meat is mostly modified atmosphere packed in trays with the modified atmosphere exhibiting a high level of O<sub>2</sub> (around 80%) and the rest is CO<sub>2</sub>. The high level of O<sub>2</sub> maintains a high degree of oxymyoglobin which results in a pleasant red colour for a prolonged period of time. An extremely high standard of hygiene is vital during the manufacture of minced meat because the product displays a large surface area and a large amount of O<sub>2</sub> is present within the packaging. Some minced meat is only placed on trays and wrapped with a plastic foil.

The shelf life of minced meat is determined through a combination of meat with a low bacteria count, an extremely high level of hygiene during manufacture, packing, distribution and storage of minced meat at shop level and maintaining temperatures below 4 °C all the time. In other meat and meat products, packed under a modified atmosphere and containing around

30–40% CO<sub>2</sub>, *Lactobacillus* spp. are the dominant bacteria within the microflora whilst, at lower concentrations of CO<sub>2</sub>, *B. thermosphacta* becomes the major bacterium. Cuts of deboned meat are frequently packed under vacuum for storage. The application of vacuum excludes any activity of aerobic spoilage bacteria such as *Aeromonas* spp. and *Pseudomonas* spp. and handling of packed meat takes place without the human hand touching the meat itself. Anaerobic, or facultative anaerobic, bacteria have a selective advantage with vacuum-packed meat and the absence of O<sub>2</sub> delays spoilage as spoilage in meat takes place much more rapidly through the activity of aerobic bacteria compared with anaerobic bacteria. Vacuum-packed meat does not experience any loss in weight during storage unlike unpacked meat, which is an economical benefit. However, bacteria such as *Lactobacillus* spp. and *Leuconostoc* spp. still thrive in vacuum-packed meats if they are stored at 5 °C; so the storage temperature should be kept as close to 0 °C as possible. The shelf life of DFD beef is naturally shortened because insufficient acidification occurred during rigor mortis to present a hurdle (see Chapter 4, Section 4.1). Vacuum-packed meat with a high pH value (above 6.0), such as DFD, favours growth of *Sh. putrefaciens* and psychrotrophic Enterobacteriaceae, which results in the production of H<sub>2</sub>S, leading to highly undesired odours.

Formation of gas, mostly CO<sub>2</sub>, in vacuum-packed meat or meat products is occasionally caused by *Leuconostoc* spp. but more often so by heterofermentative *Lactobacillus* spp. such as *Lb. brevis* which ferment sugars into lactic acid, acetic acid and CO<sub>2</sub> or through yeasts such as *Saccharomyces* spp. as well as several types of Enterobacteriaceae. Souring in meat and meat products is generally caused by excessive numbers of *Lactobacillus* spp., *Streptococcus* spp. and *Pediococcus* spp. Greening arises frequently because *Lb. curvatus* or *Lb. viridescens* produces hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), and the absence of the enzyme catalase by *Lactobacillus* spp. supports greening in meat products as H<sub>2</sub>O<sub>2</sub> is not broken down into water and O<sub>2</sub>. As H<sub>2</sub>O<sub>2</sub> is a strong oxidizing agent, it oxidizes myoglobin, which ultimately leads to greening. A change in the colour of meat can also be caused by *Ps. fluorescens* and is seen more often on poultry but occasionally also on red meat such as beef and pork. Unwanted mould on meat products is commonly caused by *Penicillium* spp., *Aspergillus* spp. as well as *Mucor* spp., and parameters such as the temperature, airflow and RH have to be adjusted properly to avoid growth of mould. Air-chilled chicken exhibits an *A<sub>w</sub>* of around 0.97 on the outer layer whilst water-chilled chicken displays an *A<sub>w</sub>* around 0.99, thus resulting in a shorter shelf life for water-chilled birds. Poultry nowadays is commonly stored at around –1 °C in order to maintain a ‘light’ colour and to achieve an acceptable shelf life. Spoilage of poultry starts with a bacteria count around 10<sup>7</sup>–10<sup>8</sup> per square centimetre. Pathogens such as *Salmonella* spp., *Escherichia* spp., *L. monocytogenes*, *Clostridium* spp. and *Staph. aureus* can potentially lead to severe illness. Bacteria such as *Salmonella* spp. and other cold-tolerant Enterobacteriaceae such as *Enterobacter* spp., *Klebsiella* spp., *Hafnia* spp., *Serratia* spp. and *Erwinia* spp. still present a risk because

all those bacteria demonstrate growth at temperatures below 7 °C. In vacuum-packed meat and meat products, murky and slimy purge is frequently seen, which is generally caused by *Lactobacillus* spp.

Although such slimy and murky purge is usually not spoiled from a microbiological point of view as the pH value of this purge is very low (sour), the consumer simply does not accept such visually unattractive-looking products.

Most common pathogens such as *Salmonella* spp., *Staph. aureus* and *L. monocytogenes* are killed at 72 °C, or if exposed to a temperature of 68–70 °C for a prolonged period of time. On meat products, where an even and constant impact of temperature cannot be guaranteed (such as during grilling of burgers) a core temperature of 76–78 °C is recommended to ensure proper heat treatment in all areas of the product.

Table 38.11 shows pathogens that can be divided on the basis of their tolerance to temperature; those that grow between 0 and 7 °C and those that grow between 7 and 30 °C. Some grow within both ranges.

**Table 38.11** Classifying pathogens according to their tolerance to temperature

Pathogen	0–7°C	7–30°C
<i>Listeria monocytogenes</i>	Y	Y
<i>Yersinia enterocolitica</i>	Y	Y
<i>Aeromonas hydrophila</i>	Y	Y
<i>Clostridium botulinum</i> types E and B	Y	Y
<i>Clostridium perfringens</i>	N	Y
<i>Bacillus cereus</i>	N	Y
<i>Salmonella</i> spp.	Y	Y
<i>Escherichia coli</i>	N	Y
<i>Staphylococcus aureus</i>	N	Y

Y, growth; N, no growth.

Different bacteria demonstrate resistance against different parameters.

- 1 Bacteria resistant against heat: spore-formers such as *Bacillus* spp. and *Clostridium* spp.
- 2 Bacteria resistant against low temperatures: *Pseudomonas* spp., *Aeromonas* spp., *Yersinia* spp., *Listeria* spp. and *Enterobacter* spp.
- 3 Bacteria resistant against low pH values: *Lactobacillus* spp. and *Pediococcus* spp.
- 4 Bacteria resistant against low  $A_w$ : *Staphylococcus* spp.
- 5 Bacteria with no need for O<sub>2</sub>: *Clostridium* spp. or facultative anaerobic bacteria.

Having the correct level of RH in rooms is important to avoid the growth of mould on one side and excess drying on the other side. The most common levels of RH in rooms are as follows:

boning room	45–60%
packaging rooms	50–60%
curing rooms	70–85%
salami drying rooms	72–93%
meat chillers	85–92%

The air speed (i.e. the speed of the airflow) is also an important factor in delaying bacterial growth and common air speeds are as follows:

meat chiller	0.1–0.3 m/s
freezer	0.1–0.3 m/s
salami drying room	0.05–0.8 m/s
blast freezing	3.0–4.0 m/s

### 38.10 The hurdle principle in the production of meat and meat products

The hurdle principle is based on the implementation of more than one hurdle in order to create safe meat and meat products as well as to achieve the desired shelf life. Having only one strong hurdle in place to assure safety in food nearly always causes a negative impact on the product regarding taste, flavour, texture or consistency. By applying several weaker hurdles at the same time, no individual hurdle has to be in place at an extremely high level. The sum of several weaker hurdles in place at the same time and acting in a synergistic way results in a safe product, with no negative impact on the quality of the product. Different hurdles applied at the same time disturb the homeostasis of bacteria which need to maintain certain parameters to stay alive. Preservation of food is meant to disturb the homeostasis permanently or temporarily. Many mathematical models have been created in order to determine safe products under the impact of different hurdles. Generally simultaneous hurdles are factored into the equation. The major hurdles used within these mathematical models are the pH value,  $A_w$ , level of salt, level of nitrite, and cooking and storage temperature. The most common hurdles in meat or meat products against spoilage are as follows.

- 1 A low bacteria count in meat from the beginning is essential whether it is sold as fresh meat or is being processed. Large numbers of bacteria are never beneficial and the saying ‘prevention is better than cure’ strongly applies. In particular, fermented meat products such as salami which are not heat treated are significantly safer if they have a low bacteria count to start. Heat-treated meat products require less cooking to reach a certain number of surviving bacteria and reduced thermal treatment generally results in a more succulent and tasty product.
- 2 Storing meat and meat products at or below 4 °C is another important hurdle, despite the fact that bacteria such as *L. monocytogenes*, *Y.*

*enterocolitica* and *Aeromonas hydrophila* can grow at those temperatures. In particular, for raw meat, the combination of a low initial bacteria count and low storage temperature is critical for a long shelf life. The optimal storage temperature of meat and most meat products is between  $-1$  and  $2$  °C and every single degree Celsius below  $4$  °C closer to  $0$  °C extends shelf life significantly.

- 3 Vacuum packing of meat eliminates aerobic spoilage bacteria and has a significant impact on extending shelf life. The vacuum applied has to be at the highest possible level ( $-0.98$  bar or higher) and the bags utilized must be properly sealed. Bags should demonstrate high barrier characteristics against  $O_2$  and moisture. Modified-atmosphere packaging of meat products with around 20–40%  $CO_2$  and 60–80%  $N_2$  also extends shelf life as  $CO_2$  forms carbonic acid and it is thus an effective hurdle against Gram-negative bacteria such as *Pseudomonas* spp. and moulds.  $CO_2$  favours the dominance of *Lactobacillus* spp. which constitute a very effective competitive flora against countless other bacteria such as *L. monocytogenes*.  $CO_2$  by itself also interferes with the metabolic activities in many bacteria and as such delays growth. The combination of  $CO_2$  in conjunction with low storage temperatures (around  $0$  °C) in meat and meat products maintains a serious hurdle against microbiological growth.
- 4 The addition of different acids inflicts different pH values on the meat products which impact on the growth of the microorganism at different levels. Lactic acid presents only a very weak hurdle in keeping bacterial growth under control whilst other acids exhibit a more profound impact. The acids, in order of effectiveness, at similar proportions are as follows: lactic acid, acetic acid, propionic acid, sorbic acid and benzoic acid, with benzoic acid being the strongest hurdle. Different acids, even of the same pH level, impact upon bacterial growth differently depending on their degree of dissociation, once penetrating into the bacterial cell. At similar pH values, different acids are more or less dissociated and only undissociated acid molecules penetrating into the bacterial cell display antimicrobial properties. Once in the cell, undissociated acid molecules release a proton ( $H^+$ ) which reduces the internal pH value of the bacterial cell, thus slowing down metabolic activity. The bacterial cell tries to remove the  $H^+$  ion which requires energy, thus leaving less energy for growth. Finally, the energy required for the removal of  $H^+$  ions is produced in an anaerobic way within the cell thus leading to even more cell-internal acidification. That explains why acetic acid is more effective than lactic acid against bacteria at similar pH values because acetic acid is less dissociated at the same pH level than lactic acid is.
- 5 The  $A_w$  value is an important hurdle in countless meat products such as salami and in cured and dried products such as prosciutto. At the same  $A_w$  value, salt inhibits the growth of bacteria more effectively than sugar. An exception is *Staph. aureus*, which is inhibited more by sugar than by salt at similar  $A_w$  levels. Xerophile microorganisms prefer low levels of

$A_w$  for growth and moulds especially fall into this group. Some species of mould can grow at  $A_w$  values as low as 0.63 although their optimum is an  $A_w$  between 0.86 and 0.91. Halophile microorganisms are salt loving and require sodium ions for their growth, the species of the genus *Halobacterium* belong to this group. Extreme halophile bacteria require a salt concentration of 12–15% for living whilst moderate halophile organisms require a salt concentration of 1–8% for growth.

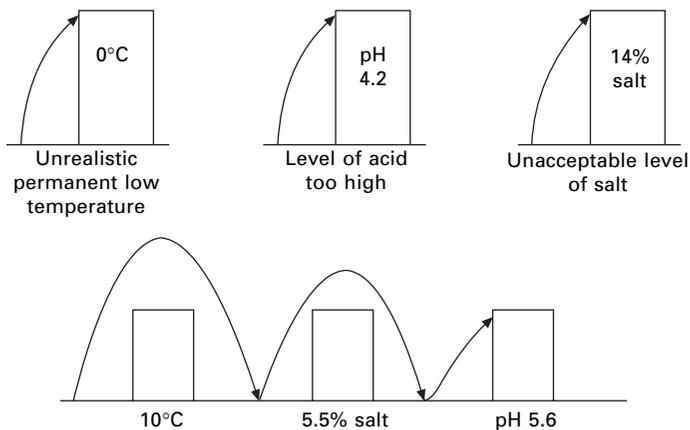
- 6 Processes such as oxidation and reduction are generally not positive in meat and a decreased redox potential ( $E_h$  value) favours the growth of lactic acid bacteria. As a result, a reduced  $E_h$  value inhibits the growth of aerobic spoilage bacteria such as *Pseudomonas* spp. and *B. thermosphacta*, and spoilage induced by such aerobic bacteria commonly takes place at a much faster rate than spoilage from lactic acid bacteria. Overall, the reduction in  $E_h$  value makes meat products safer from a microbiological standpoint and results in extended shelf life. *Clostridium* spp. are the major exception to this rule as those bacteria are obligate anaerobic and only grow in the absence of  $O_2$ .
- 7 Preservatives such as food acids, nitrite, smoke, lactate, acetate, polyphosphates, antioxidants (ascorbic acid and ascorbate), bacteriocins, phenols and SMBS (see Chapter 6, Section 6.4.1) are effective against bacterial growth. Strains of *Leuconostoc carnosum* are known for producing effective bacteriocine (which are proteins) exhibiting excellent inhibitory effects on products such as hot dogs or sliced ham. The problem is finding an effective application of this bacterium into packed food; spraying the solution on to the product before being packed but after being sliced could be the answer. In salami, the same bacterium could be directly introduced into the sausage mass. Nisin is a polypeptide and a bacteriocine produced by *L. lactis* subsp. *lactis*. It is a natural preservative but in some countries not permitted. The effectiveness of nisin as a hurdle must also be seen in conjunction with other hurdles present at the same time within a meat product. Nisin suppresses eventual sporulation of *Bacillus* spp. and *Clostridium* spp. and as such is useful in canned food which has to be shelf stable under tropical conditions. Another bacteriocine is sacacin produced by a strain of *Lb. sake* which acts well against the growth of *L. monocytogenes*. Nitrite, like sulphite, acts more effectively at lower pH values in meat products. In cured and cooked products, the effect of nitrite as a hurdle against spoilage is often overrated and other parameters such as the initial bacteria count, the intensity of thermal treatment to achieve the desired core temperature or  $F$  value and the storage temperature of a meat product have a much more significant impact on the shelf life than the level of nitrite does. The presence of some nitrite is of some advantage but the impact of residual nitrite, as stated, should not be overrated because the minimum level needed to present an effective hurdle is around 100–140 ppm.
- 8 Introducing a competitive flora into meat products such as salami by

adding starter or protection cultures counteracts the microflora present and stabilizes the meat product. The establishment of a competitive flora, primarily lactic acid bacteria, is also of importance in fresh meat to extend shelf life. Bacteria such as *L. carnosum* 4010 suppress the growth of bacteria on sliced products as well as portioned meat products such as hot dogs.

- 9 Proper thermal treatment of cooked (pasteurized) as well as retorted (sterilized) products safely eliminates vegetative spoilage bacteria and pathogens as well as spores. Generally, a core temperature of 72 °C during pasteurizing is sufficient and products can also be pasteurized, or retorted, on the basis of  $F$  value and not purely on core temperature. By utilizing the  $F$  value, the two factors for applying certain temperatures for a certain period of time are considered together to achieve the desired killing effect (see Chapter 40), resulting in the product's safety and desired shelf life.
- 10 Hygiene can also be considered a hurdle, although it is impossible to quantify this parameter. High levels of hygiene from both factory and staff have an enormous impact on shelf life of meat and meat products.

**Table 38.12** Basic guidelines for hurdles to prevent spoilage

Hygiene status of meat and staff	High
Storage temperature	Low
pH value	Low
$A_w$	Low
$E_H$ value	Low
Heat treatment ( $F$ value)	High
Preservatives	Present
Competitive flora	Present
Packaging	Present



**Fig. 38.2** Principles of hurdle technology.

Table 38.12 shows the basic guidelines against microbiological spoilage through the introduction of different hurdles which can be present on their own or preferably in combination. Figure 38.2 displays the basics of hurdle technology. Individual hurdles would be impractical but a number of moderate hurdles used in combination stabilize the product.

## 39

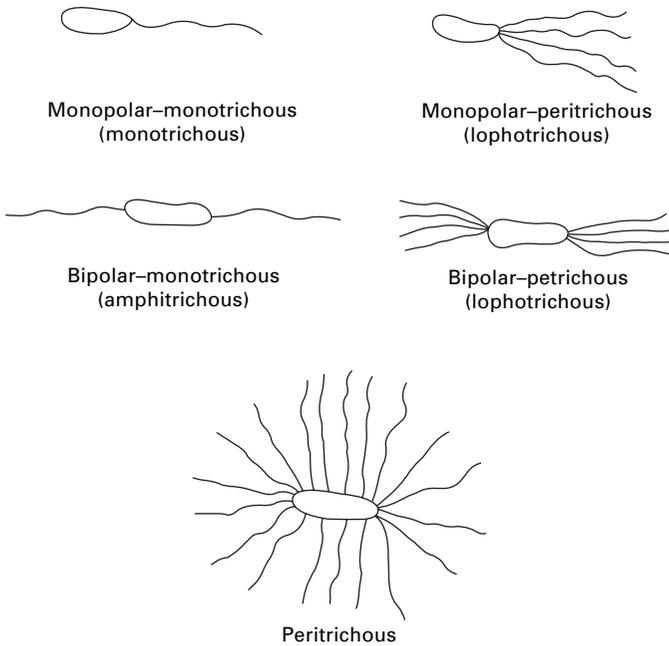
# The microbiology of specific bacteria

Bacteria are single-celled (unicellular) organisms. Their size varies from 0.4 to 1.5  $\mu\text{m}$  (1  $\mu\text{m}$  = 0.001 mm) and most are visible under a light microscope. The majority are 1–10  $\mu\text{m}$  long. They vary in shape and can be spherical, ovoid, elongated, spiral or rod like in form and individual bacteria form chains, clusters, groups or pairs. Bacteria are procaryotes as they lack a true cell nucleus. Their genetic material in the form of a nucleoid instead lies in the cytoplasm and is not enclosed in a nuclear membrane. Bacteria have both DNA and ribonucleic acid and reproduce asexually via binary fission, i.e. splitting into two with one cell dividing into two equal daughter cells. They usually prefer a pH value near neutral, between 5.5 and 6.0, for their growth.

### 39.1 Flagella in bacteria

A large number of bacteria have flagella which are made out of polypeptides. The rotary action (up to 2500 rev/min) of the flagella makes a bacterial cell move. Flagella are between 15 and 25  $\mu\text{m}$  in length and between 0.2 and 0.8  $\mu\text{m}$  in diameter and are firmly attached to the membrane of the cell as well as to the cell body itself. They are made up of three major parts: a long hair-like filament containing the helical protein flagellin, a hook which attaches this filament to the cell membrane and the body of the flagellum itself. Flagellation (the arrangement of the flagella) can either be peritrichous (flagella all over the cell surface) or polar (the flagella attached to one end). If flagellation is monopolar, flagella are only attached to one end but, when it is bipolar, they are attached to both ends. Polar flagella can consist of only one flagellum (monopolar–monotrichous arrangement) or a bundle of flagella (monopolar–

peritrichous arrangement). Having one flagellum on both ends of the cell is referred to as bipolar–monotrichous flagellation, while a bundle of flagella on both ends is a bipolar–peritrichous arrangement. If there is a single flagellum at each end of the cell, the flagellation is described as amphitrichous whilst having a bundle of flagella at one or both ends of the cell can be described as lophotrichous flagellation. As examples, Enterobacteriaceae have peritrichous flagella whereas Pseudomonadaceae have polar flagella. Figure 39.1 shows differently flagellated cells.



**Fig. 39.1** Types of arrangement of flagella on bacteria.

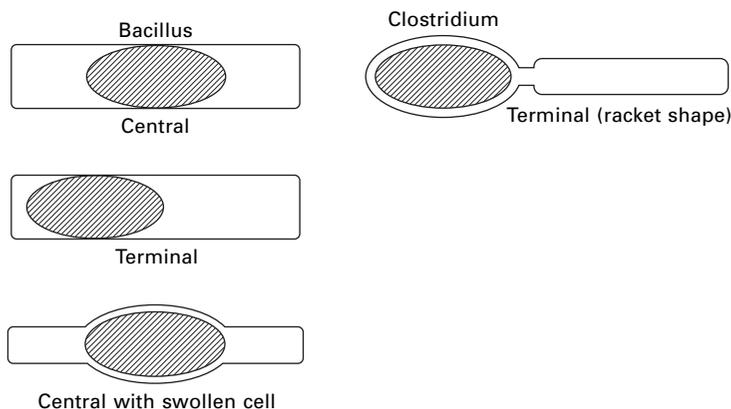
### 39.2 Spore formation in bacteria

Members of the family Bacillaceae such as *Bacillus* spp. and *Clostridium* spp. can form spores. These spores are known as endospores, as they are formed inside the bacteria. They can be round, oval, kidney shaped, ellipsoidal or banana shaped. Spores are a form of survival mechanism for the cell, used during times of need such as when there is a lack of water or nutrients. When conditions are bad, a spore-forming bacterium gathers nutrients and other food reserves and produces a hard and solid protective coat, which protects its nuclear core. The remainder of the cell dies and, once living conditions improve again, a new vegetative cell is built from the spore.

The water content of bacterial spores is only around 12–15% and they are not metabolically active on their own. Spores are very resistant to heat. Spore-forming bacteria, just like many other bacteria, are killed within a few minutes at a temperature of 90 °C whereas the bacterial spores are destroyed only if exposed to significantly higher temperatures (above 115–120 °C) for several minutes. Spore formation in food generally does not take place at pH levels below 4.3 as spore-forming bacteria are not active in such acid conditions. Bacteria do not sporulate at temperatures below 10 °C, a fact that is useful to bear in mind when producing thermally treated products which are subsequently cooled. Figure 39.2 shows different types of endospore.

Fungi such as yeasts and moulds also produce spores but exclusively as a means of reproduction rather than survival. There are several differences between bacterial spores and the spores produced by yeasts or moulds. Moulds produce exospores (cell built outside the cell body) while yeasts produce endospores as well as exospores. Spores from yeast and mould are also destroyed during pasteurization whereas bacterial spores require much more severe heat treatment to be killed.

Table 39.1 shows important bacteria and fungi found in meat and meat products. Figure 39.3 shows the shapes of common bacteria found in meat and meat products.



**Fig. 39.2** Different types of endospore.

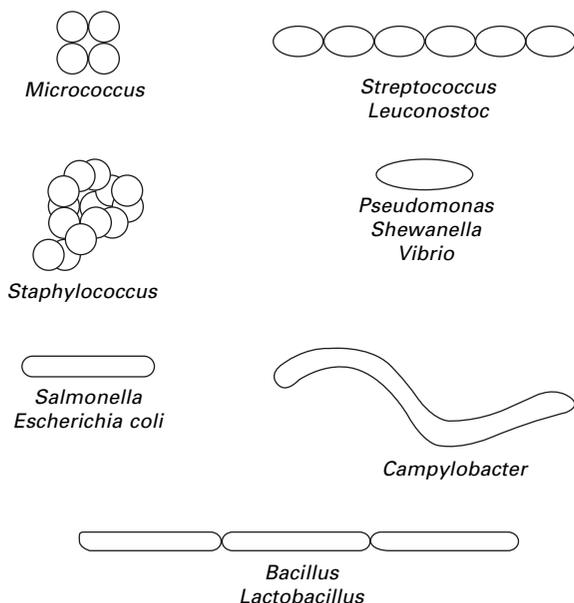
### 39.3 Family Micrococcaceae

#### 39.3.1 Genus *Staphylococcus*

*Staphylococcus* is an important genus within the Micrococcaceae family. *Staphylococcus aureus* is a significant bacterium in this genus as it can cause food poisoning. Other species of *Staphylococcus*, such as *Staph. xylosus* and *Staph. carnosus*, are used as starter cultures for salami. They produce the enzyme catalase, which breaks down hydrogen peroxide ( $H_2O_2$ ) into water

**Table 39.1** Major bacteria and fungi related to meat

Family	Genus	Species
Spirillaceae	<i>Campylobacter</i> <i>Spirillum</i>	<i>Campylobacter jejuni</i>
Pseudomonadaceae	<i>Pseudomonas</i>	<i>Pseudomonas fragii</i> <i>Pseudomonas fluorescens</i>
Enterobacteriaceae	<i>Shewanella</i>	<i>Shewanella putrefaciens</i>
	<i>Salmonella</i>	<i>Salmonella typhi</i> <i>Salmonella typhimurium</i> <i>Salmonella enteritidis</i>
	<i>Escherichia</i>	<i>Escherichia coli</i>
	<i>Shigella</i>	<i>Shigella sonnei</i> <i>Shigella flexneri</i> <i>Shigella boydii</i> <i>Shigella dysenteriae</i>
	<i>Yersinia</i>	<i>Yersinia enterocolitica</i>
	<i>Citrobacter</i>	
	<i>Klebsiella</i>	
	<i>Proteus</i>	
	<i>Hafnia</i>	
	<i>Aeromonas</i>	
Aeromonaceae	<i>Aeromonas</i> <i>Vibrio</i>	<i>Aeromonas hydrophila</i> <i>Vibrio cholerae</i> <i>Vibrio parahaemolyticus</i> <i>Vibrio vulnificus</i>
Micrococcaceae	<i>Micrococcus</i>	<i>Micrococcus varians</i>
Streptococcaceae	<i>Staphylococcus</i>	<i>Staphylococcus aureus</i>
	<i>Streptococcus</i> <i>Leuconostoc</i>	<i>Leuconostoc mesenteroides</i> <i>Leuconostoc carnosum</i>
Bacillaceae	<i>Pediococcus</i>	
	<i>Enterococcus</i>	
	<i>Bacillus</i> <i>Clostridium</i>	<i>Bacillus cerus</i> <i>Clostridium botulinum</i> <i>Clostridium perfringens</i> <i>Clostridium sporogenes</i>
Lactobacillaceae	<i>Lactobacillus</i>	<i>Lactobacillus brevis</i> <i>Lactobacillus curvatus</i> <i>Lactobacillus viridescens</i>
	<i>Brochothrix</i>	<i>Brochothrix thermosphacta</i>
Listeriaceae	<i>Listeria</i>	<i>Listeria monocytogenes</i>
Moniliaceae	<i>Penicillium</i>	<i>Penicillium viridicatum</i>
	<i>Aspergillus</i>	<i>Aspergillus flavus</i> <i>Aspergillus niger</i> <i>Aspergillus fumigatus</i>
	<i>Candida</i>	<i>Candida famata</i>
Cryptococcaceae	<i>Candida</i>	
Mucoraceae	<i>Mucor</i>	
	<i>Rhizopus</i>	
Saccharomycetaceae	<i>Saccharomyces</i>	<i>Saccharomyces cerevisiae</i>
	<i>Debaryomyces</i>	<i>Debaryomyces hansenii</i>



**Fig. 39.3** Shapes of common bacteria in meat.

and oxygen ( $O_2$ ). *Staphylococcus* spp. are ubiquitous and around 40–50% of all adults carry *Staph. aureus*. The size of staphylococci ranges from 0.7 to 1.2  $\mu\text{m}$  and colonies of staphylococci are clearly defined, convex or round and about 3.5 mm in diameter.

*Staph. aureus* is a non-motile, mesophilic Gram-positive facultative anaerobic spherical bacterium which produces five enterotoxins. Colonies of *Staph. aureus* are white to orange in colour and the bacteria are present in clusters rather than chains. It is the toxins produced which are responsible for food poisoning and toxic shock syndrome, rather than the bacteria itself. *Staph. aureus* toxins are heat stable and even slightly resistant to trypsin digestion in the stomach. Their incubation time is 2–6 h and they cause symptoms such as vomiting and diarrhoea, but not fever. The infectious dose of *Staph. aureus* is  $10^6$  per gram of food and the heat-stable toxins will still be present in food even if the bacterium itself has already been killed.

*Staph. aureus* is a typical pathogen found in meat products. It is coagulase positive and so can be detected using the coagulase test. Coagulase is an extracellular substance produced by bacteria such as *Staph. aureus* and, to perform this test, a sample is inoculated into blood plasma and incubated. If a coagulase-positive bacterium is present within the sample, blood clots will form as a result of the reaction of coagulase with prothrombin, which is present in blood.

*Staph. aureus* grows at temperatures between 7 and 45  $^{\circ}\text{C}$ . The optimum temperature for growth is 37  $^{\circ}\text{C}$ . Storage of meat and meat products below 7  $^{\circ}\text{C}$  is the most simple and effective hurdle to prevent growth. The optimal

pH value for growth is 7.2–7.6 and production of toxins stops at a pH below 5.2 or an  $A_w$  below 0.90. Growth of the bacterium itself is halted at an  $A_w$  below 0.86. *Staph. aureus* is capable of anaerobic growth but prefers aerobic conditions. If growing anaerobically, it ferments a wide range of sugars primarily into lactic acid but, under aerobic conditions, it ferments glucose into carbon dioxide ( $\text{CO}_2$ ) and acetate. Sliced products are commonly the cause of human infection with *Staph. aureus*. *Staph. aureus* is also readily found in sliced vacuum-packed or modified-atmosphere-packed cooked meat products but their numbers are generally small, usually owing to the action of competitive flora such as lactic acid bacteria.

### 39.3.2 Genus *Micrococcus*

*Micrococcus* spp. are Gram-positive aerobic spherical cocci. They are catalase positive, reduce nitrate to nitrite and are usually non-motile. Some species such as *Micrococcus varians* have been used for a long time as a starter culture in salami because of their contribution to development of curing colour and flavour. The presence of the enzyme nitrate reductase in *Micrococcus* spp. plays a role in the reduction of nitrate to nitrite and as a result stabilizes the red curing colour in meat products. The enzyme catalase, also found in *Micrococcus* spp., breaks down  $\text{H}_2\text{O}_2$  into water and  $\text{O}_2$ , which is of benefit to the colour and flavour of meat products. Deactivating  $\text{H}_2\text{O}_2$  is beneficial as presence of this compound speeds up the development of rancidity in products such as salami.  $\text{H}_2\text{O}_2$  is also an extremely strong oxidizing agent, therefore having a negative impact on colour.

## 39.4 Family Streptococcaceae

### 39.4.1 Genus *Pediococcus*

*Pediococcus* spp. belong to the family Streptococcaceae and are also lactic acid bacteria. They are Gram positive, generally catalase negative, non-motile and present predominantly in pairs or tetrads. Certain species of *Pediococcus* such as *Pediococcus acidilactici* are used as starter cultures in salami as they ferment glucose, mannose and fructose into acid (mainly lactic acid) without producing gas, as it is the case with homofermentative lactic acid bacteria. *Pediococcus* spp. also do not produce the enzyme nitrate reductase.

### 39.4.2 Genus *Leuconostoc*

*Leuconostoc* spp. are mesophile, Gram positive, facultative anaerobic, non-motile and non-spore-forming cocci which do not contain the enzyme catalase. They require a pH at or above 4.8 to survive. Some strains are applied as starter cultures in dairy products and fermentation of cabbage to sauerkraut also depends to a large degree on bacteria of these species. They are not used

as starter cultures for meat products, however. In meat products, *Leuconostoc* spp. cause souring by producing lactic acid and acetic acid through fermentation of carbohydrates, formation of slime and discolouration (greening). Slime can be seen occasionally in salami when *Leuconostoc mesenteroides* metabolizes sugar (predominantly sucrose) at increased fermentation temperatures and slime is one of the by-products. *L. carnosum* is often found in spoiled vacuum-packed meat. This is because it is anaerobic and grows well at temperatures as low as 1–4 °C, often dominating over other bacteria. *L. carnosum* 4010 produces a highly effective bacteriocin, however, which inhibits growth of pathogens such as *L. monocytogenes*.

### 39.4.3 Genus *Streptococcus*

*Streptococcus* spp. are Gram positive, facultative anaerobic, catalase negative bacteria and spherical or ovoid in shape. Some species such as *Streptococcus faecalis* and *Strep. faecium* produce different types of gas which contribute to spoilage of meat. The optimum temperature for growth is around 36 °C. *Streptococcus* spp. arrange themselves into chains, with as few as four or as many as 40 cocci in a chain.

## 39.5 Family Enterobacteriaceae

Enterobacteriaceae are facultatively anaerobic, Gram-negative and rod shaped bacteria. They also ferment glucose producing organic acids such as lactic acid and acetic acid. Enterobacteriaceae are around 2 µm in length and around 0.4 µm in diameter. Most are motile and require an  $A_w$  above 0.95 and a pH at or above 4.5 in order to live. The most important members of the family Enterobacteriaceae in meat and meat products are the greater *Escherichia*, *Shigella*, *Salmonella*, *Citrobacter*, *Enterobacter*, *Klebsiella*, *Hafnia*, *Serratia*, *Proteus* and *Yersinia*. Enterobacteriaceae are good indicators of the level of hygiene in a factory. If large numbers are present, this indicates poor hygiene practices. Enterobacteriaceae are generally killed during pasteurization of a meat product if temperatures of 70 °C are reached in the core.

### 39.5.1 Genus *Escherichia*

*Escherichia coli* belong to the genus *Escherichia* which is named after Theodor Escherich. Most *Escherichia* spp. ferment glucose into hydrogen and CO<sub>2</sub> at a ratio of 1:1. Hundreds of different strains of *E. coli* live harmlessly in the human digestive system but some strains are able to produce powerful toxins. Two types of enterotoxin are produced by enterotoxigenic *E. coli*, one of which is heat stable and the other of which is heat labile. The heat-stable toxin is not even destroyed by heating at 100 °C for 35 min. The heat-labile

toxin, however, which is more common, is destroyed if exposed to 65 °C for 30 min. Some strains of *E. coli* are known as enterohaemorrhagic *E. coli*, also known as verotoxin-positive *E. coli*. Other pathogenic types of *E. coli* are enteropathogenic *E. coli* and enteroinvasive *E. coli*.

The most common isolated enterohaemorrhagic *E. coli* is O157:H7. Enterohaemorrhagic *E. coli* cause bloody diarrhoea and abdominal cramps (or haemorrhaging) by invading the intestinal tract (entero means relating to the intestines). The disease can be much more severe in the old or very young owing to the significant loss in fluids and electrolytes (i.e. gastroenteritis) caused by the verotoxin. The onset of the symptoms occurs 12–72 h after infection and the infective dose is very low, only about 10–100 organisms of *E. coli*. *E. coli* O157:H7 is Gram negative, facultative anaerobic and mesophilic and requires a pH range of 4.5–8.8 as well as an  $A_w$  above 0.95 to multiply. Under perfect living conditions, *E. coli* doubles in numbers within 20–30 min. Optimum growth for *E. coli* O157:H7 happens at 37 °C and it also survives freezing. Undercooking of meat products such as hamburgers is a frequent reason for food poisoning caused by *E. coli* O157:H7 but, if meat is cooked to temperature of 70–72 °C, the bacteria are inactivated. In general, cooking meat properly and storing it below 4 °C are the best ways to prevent growth of *E. coli* O157:H7. The pathogen is a particularly significant problem in raw fermented salami as even elevated levels of nitrite do not prevent its growth greatly.

### 39.5.2 Genus *Salmonella*

The genus *Salmonella* is named after the American microbiologist D. E. Salmon. They are Gram-negative, rod shaped, non-spore forming, usually motile and aerobic or facultative anaerobic; around 1400 serovars are known. Species such as *Salmonella typhi*, *S. typhimurium* and *S. enteritidis* are particularly of relevance in meat technology. *Salmonella* spp. ferment glucose and maltose into gas and acid but do not ferment lactose. The optimum temperature for their growth is 37 °C but they can grow at temperatures between 5 and 45 °C. *Salmonella* spp. are effectively destroyed by a temperature of 72 °C but present a danger if undercooked and raw meat products are consumed containing live bacteria. *Salmonella* spp. require an  $A_w$  above 0.95 and a pH above 5.5 in order to produce toxins, and they require an  $A_w$  at or above 0.92 and a pH above 4.4 for growth. The endotoxins produced are heat labile.

Once *Salmonella* spp. are present in the intestines and start to grow, when numbers reach the vicinity of  $10^5$ – $10^6$ , sufficient toxins are released to cause illness. The number of *S. typhi* required to cause illness is much lower, however, and is below  $10^2$ . Poultry, pork and minced meat commonly contain *Salmonella* spp. which cause foodborne disease. Salmonellosis typically causes fever, diarrhoea, vomiting and septicaemia. The fever caused by *S. typhi* is known as typhoid fever. Gastroenteritis is the most common form of

salmonellosis and can be caused by any of the serotypes of *S. enteritidis*. Symptoms appear 10–16 h after ingestion and include causing vomiting, abdominal cramps, headache and diarrhoea. These conditions may last for 3–7 days. Symptoms of typhoid fever are headache, weakness, pain and loss of appetite. The best prevention of salmonellosis is proper cooking of foods and storage of food below 5 °C.

### 39.5.3 Genus *Shigella*

The genus *Shigella*, named after the Japanese microbiologist K. Shiga, are related to the genus *Salmonella*. They are Gram-negative rod-shaped non-motile non-spore-forming bacteria. The genus consists of four species: *Shigella boydii*, *Sh. dysenteriae*, *Sh. flexneri* and *Sh. sonnei*; all four are pathogenic. Shigellosis causes bloody diarrhoea. The infective dose of *Sh. sonnei* or *Sh. flexneri* is  $10^2$ – $10^4$  cells and symptoms start to appear after around 24–72 h.

### 39.5.4 Genus *Proteus*

*Proteus* spp. are in the shape of straight rods and are extremely motile owing to their peritrichous flagella. They are aerobic or facultative anaerobic bacteria and Gram negative. *Proteus* spp. cause spoilage in fresh meat as they metabolize amino acids, creating intense off-flavours and slime. *Proteus* spp. can also form a toxic lipopolysaccharide.

### 39.5.5 Genus *Enterobacter*

*Enterobacter* spp. are Gram-negative motile rods and are usually peritrichously flagellated. *Enterobacter* spp. are found in a wide variety of food as they can grow in a wide temperature range and are very adaptable in terms of the nutrients that they require to survive. *Enterobacter* spp. in meat products cause off-flavour, produce gas and form slime as a metabolic by-product.

### 39.5.6 Genus *Yersinia*

In terms of meat products, *Yersinia enterocolitica* is the most important representative of this genus. It is a Gram-negative facultative anaerobic bacterium and is ovoid or rod like in shape. It is psychrotrophic and shows growth at temperatures as low as –1 °C but is able to grow up to a temperature of 42 °C. Its optimal temperature for growth is around 26 °C. It thrives in a wide pH range (between 4.4 and 9.2) and requires an  $A_w$  above 0.92 to survive. *Y. enterocolitica* is often found in oysters and milk as well as meat. The infective dose has not yet been securely determined, but illness (which occurs through ingestion of the live organisms) seems to result at levels between  $10^2$ – $10^3$  per gram of food. The incubation period is 24–36 h but can be up to 7 days. Illness lasts for around 2 weeks and the symptoms are fever,

nausea, vomiting and diarrhoea. *Yersinia* spp. can tolerate salt levels up to 7% and survive well in vacuum-packed meat stored at 1 °C. *Y. enterocolitica* can be expected to be present in essentially all meat chillers. The best way to delay its growth is to store meat below 5 °C.

## 39.6 Family Pseudomonadaceae

### 39.6.1 Genus *Pseudomonas*

*Pseudomonas* spp. belong to the family Pseudomonadaceae and are psychrophilic catalase-positive obligate aerobic (i.e. they require presence of O<sub>2</sub> to survive) Gram-negative bacteria. They are usually single curved (banana like) or in the shape of straight rods. They are made mobile by polar flagella. Members of this family can be expected to be present in every meat chiller but only a few are associated with human disease. They grow at temperatures between 0 and 41 °C and some strains such as *Pseudomonas fragii* even grow at temperatures as low as -6 °C. *Ps. fluorescens* also grows at temperatures as low as -4 °C. *Pseudomonas* spp. require a high  $A_w$  (above 0.97) to survive and the pH must be at or above 4.5. Levels of *Pseudomonas* spp. in excess of 10<sup>7</sup>-10<sup>8</sup> per square centimetre on the surface of meat lead to the formation of slime and off-flavours. Some groups of *Pseudomonas* spp. are more responsible than others for the spoilage of meat. *Ps. fragii* as well as *Ps. fluorescens*, for example, break down or metabolize the resulting amino acids leading to highly undesirable off-flavours.

### 39.6.2 Genus *Shewanella*

*Shewanella putrefaciens* is another spoilage bacterium belonging to the family Pseudomonadaceae. It is also Gram negative. This bacterium produces hydrogen sulphide (H<sub>2</sub>S), causing highly undesirable off-flavours in meat.

## 39.7 Family Bacillaceae

Members of the family Bacillaceae are Gram-positive bacteria. Most are rod shaped whereas some are spherical and they can produce endospores. Some, such as members of the genus *Bacillus* can be aerobic as well as facultative anaerobic, but *Clostridium* spp. are obligate anaerobic. Most Bacillaceae have peritrichous flagella.

### 39.7.1 Genus *Bacillus*

The genus *Bacillus* contains 48 recognized species, which produce heat-resistant endospores. Only around 10% of the members of the genus *Bacillus*

produce gases such as CO<sub>2</sub> through the fermentation of sugar. *Bacillus* spp. are mesophilic bacteria and grow best at temperatures of around 30–35 °C. They have peritrichous flagella. *Bacillus anthracis* is the aetiological agent of anthrax in animals and humans. It grows in colonies with 36 °C being the optimum temperature for growth and 7.0 (i.e. neutral) the optimum pH. *B. cereus* is quite similar to *B. anthracis* except that it is much more motile. *B. cereus* is a facultative anaerobic Gram-positive spore-forming rod and causes two distinct forms of food poisoning. Food poisoning is related to the presence of the heat-resistant spores of the bacterium which survive cooking. Once the temperature within the food is reduced, the spores germinate and enterotoxins are produced. The two different types of food poisoning are the diarrhoeal type caused by strains of *B. cereus* which produce heat-sensitive enterotoxins and the emetic type caused by strains of *B. cereus* which form heat-stable enterotoxins. The emetic type can cause short-incubation gastroenteritis for which the incubation time is only around 3–8 h. The symptoms include severe nausea and vomiting. Food which is kept warm for a prolonged period of time is frequently the cause of the emetic type of food poisoning. The diarrhoeal type can cause long-incubation gastroenteritis for which the incubation time is around 16–18 h. Symptoms are abdominal cramps and diarrhoea. In the case of the diarrhoeal type the infective dose is around 10<sup>6</sup>–10<sup>8</sup> per gram of food whereas the infective dose of the emetic type is only around 10<sup>3</sup>–10<sup>6</sup> per gram of food. Temperatures below 10 °C stop *B. cereus* from sporulating and so the best prevention method is to store meat and meat products below 5 °C.

### 39.7.2 Genus *Clostridium*

The genus *Clostridium* includes bacteria which are Gram positive, spore forming, rod like in shape and obligate anaerobic. They generally have peritrichous flagella. *Clostridium* spp. are mesophilic and grow best around 20–25 °C. They produce spherical or ovoid spores and most *Clostridium* spp. (around 90%) produce gases during fermentation. The gas predominantly produced is H<sub>2</sub>S which creates very smelly and objectionable off-flavours.

*Clostridium perfringens* is a non-motile obligate anaerobic rod and its spores are heat resistant and not destroyed by normal cooking temperatures. *Cl. perfringens* is found in around 30% of healthy people. It can produce serious food poisoning, however, by producing enterotoxins in the intestines which leads to severe abdominal pain, diarrhoea, fever as well as vomiting. Once the bacteria are in the human intestine and have started to sporulate the toxins are formed, producing six types of enterotoxin (A to F). The incubation period is 8–14 h after digestion and the infective dose is 10<sup>6</sup>–10<sup>8</sup> per gram of food. *Cl. perfringens* can grow at temperatures between 15 and 50 °C and at pH levels between 4.9 and 8.3 but it requires a high A<sub>w</sub> (0.98) for growth. It has the ability to grow very quickly at temperatures around 45 °C, causing problems if cooked food is not cooled quickly. Very slow cooling of large

joints of meat and whole chickens or turkeys favours the growth of *Cl. perfringens*. Its heat resistance is much less than that of *Cl. botulinum* or *Cl. sporogenes*. Vegetative cells of *Cl. perfringens* are destroyed at temperatures above 62 °C and spores can withstand temperatures of 95–100 °C for 1 h.

The best way to prevent illness due to *Cl. perfringens* is to cool cooked meat products quickly below 7 °C. If they are reheated or kept warm, they must reach a temperature of above 70 °C.

*Cl. botulinum* is a motile peritrichous flagellated spore-forming obligate anaerobic mesophilic bacterium. It is found ubiquitously in soil. The word 'botulinum' comes from the Latin word 'botulus' meaning sausage. It is of great significance to processors of meat and meat products as it produces one of the most potent poisons known. Because death can be the result of botulinum poisoning, the 12D concept was introduced to reduce safely the risk of food poisoning caused by *Cl. botulinum* (see Chapter 40, Section 40.3). Symptoms of botulism are blurred speech, double vision and progressive paralysis of respiration, which can ultimately cause death. The heat-labile exotoxin produced by the bacterium is a neurotoxin, which blocks the transmittance of neurosignals, thus eventually causing paralysis of the breathing system. Symptoms can be seen after 12–48 h after infection occurred. The fatal dose of the poison produced by *Cl. botulinum* for humans is around 1.0 µg (1/1 000 000 or 10<sup>-6</sup> g). The neurotoxin is destroyed, however, by heat treatment at 82 °C for around 60 min.

Seven different types of *Cl. botulinum*, types A–G, are known. Botulism in humans, however, is caused by only serovars A, B, E and F; A, B and E are the most significant serovars in meat technology. *Cl. botulinum* types A and B grow at temperatures above 10 °C, pH levels between 4.7 and 8.0 and an  $A_w$  above 0.95. This explains why salted cured meat products (see Chapter 23, Section 23.3) have to be stored chilled until an  $A_w$  of 0.95 is reached before the salted meat product can be exposed to higher temperatures.

*Cl. botulinum* is a particular threat in canned food and raw air-dried products. The botulin toxins are only produced if *Cl. botulinum* can grow and, in order to grow, the absence of O<sub>2</sub> (anaerobic conditions) is vital. Nitrite in canned cured meats prevents germination of spores but home-canned cured meats can cause botulism if the canned meat is insufficiently thermally heat treated.

The botulinum cook (see Chapter 40, Section 40.3) is required to ensure that a canned meat product is safe and this usually involves cooking to an  $F_{121,1}$  value of 2.6–3 min with a reference temperature of 121 °C. Alternatively, an  $F_{121,1}$  value of 30 min at 111 °C gives the same result. Some type E, B and F strains of *Cl. botulinum* can be non-proteolytic and psychrotrophic and these grow at temperatures as low as 3.5 °C. Since they are non-proteolytic, their growth cannot be detected in food as no off-flavour is produced.

Unlike *Cl. botulinum* and *Cl. perfringens*, *Cl. sporogenes* is non-pathogenic but produces large amounts of highly undesirable odours such as H<sub>2</sub>S in canned food.

## 39.8 Family Lactobacillaceae

Within the family Lactobacillaceae two genera, *Lactobacillus* and *Brochothrix*, are of importance in meat technology.

### 39.8.1 Genus *Lactobacillus*

*Lactobacillus* spp. are members of the family Lactobacillaceae. They are psychrophilic, non-spore forming, rod shaped, non-motile, Gram positive and facultative anaerobic. *Lactobacillus* spp. do not contain the enzyme catalase. Homofermentative *Lactobacillus* spp. ferment sugars predominantly into lactic acid (more than 90%) and do not produce gas. Heterofermentative species, on the other hand, ferment sugar (glucose) into lactic acid besides other substances such as acetic acid and produce CO<sub>2</sub>. The production of gas is regularly the cause for food spoilage. At a pH value below 5.0 in a meat product, the conditions are more suitable for growth of heterofermentative *Lactobacillus* spp. than homofermentative *Lactobacillus* spp. Most *Lactobacillus* spp. require an  $A_w$  above 0.95 to ferment substances such as sugars. An  $A_w$  below 0.95 severely restricts growth while growth stops altogether at an  $A_w$  below 0.92. A pH above 3.2 is required for growth.

*Lactobacillus* spp. are commonly the cause of souring in meat products. Certain strains of heterofermentative *Lactobacillus* spp. also form H<sub>2</sub>O<sub>2</sub>. H<sub>2</sub>O<sub>2</sub> originating from *Lb. viridescens* and *Lb. curvatus* causes the oxidation of the colour pigment myoglobin, resulting in a grey–green or even yellow or white colour in a meat product or packed fresh meat. H<sub>2</sub>O<sub>2</sub> is only formed in the presence of O<sub>2</sub>. Discolouration such as greening can also occur, however, in vacuum-packed meat if the packaging material is faulty and is permeable to O<sub>2</sub>. Once O<sub>2</sub> penetrates into the packed cooked meat product, H<sub>2</sub>O<sub>2</sub> is produced and the product discolours. The presence of *Lb. brevis* can also cause CO<sub>2</sub> to form inside the packaging.

*Lactobacillus* spp., besides being part of the natural microflora of meat, or being introduced owing to contamination, can also be added on purpose to meat products during their manufacture. Several species of *Lactobacillus* are added as starter cultures in salami (see Chapter 16, Section 16.2.2). *Lactobacillus* spp. also act as competitive microflora in meat and meat products, extending their shelf life by competing with pathogens such as *L. monocytogenes* and not allowing them to grow excessively.

### 39.8.2 Genus *Brochothrix*

*Brochothrix thermosphacta* is a spoilage bacterium, and not a pathogen, and is related to *Listeria* spp. as well as *Lactobacillus* spp. Occasionally, *Brochothrix* spp. are even classified as members of the family Listeriaceae together with *Listeria* spp. It is a Gram-positive rod-shaped non-sporing facultative anaerobe and is non-motile. It grows at pH levels between 5.0 and 8.0 and at temperatures between 0 and 28 °C, with 20 °C being optimal. It also requires an  $A_w$  above

0.94 for growth. *B. thermosphacta* is one of the main spoilage bacteria in raw meat stored aerobically or packaged in a modified atmosphere. It also grows on vacuum-packed meat stored chilled. Growth of *B. thermosphacta* is in fact most efficient when the level of O<sub>2</sub> is reduced and CO<sub>2</sub> is present (i.e. the conditions found in modified-atmosphere packing). *B. thermosphacta* is also relatively stable against reduced  $A_w$  in fresh meat and therefore is able to outgrow other spoilage bacteria such as Enterobacteriaceae. *B. thermosphacta* causes discolouration and off-flavours in meat and meat products by breaking down fat and protein. Slime and souring are the result. These bacteria produce acetic acid and acetone from glucose under aerobic conditions, and the presence of phosphate and nitrite can even support rather than inhibit their growth, as is usually the case when phosphate and nitrite are added.

## 39.9 Family Aeromonadaceae

### 39.9.1 Genus *Vibrio*

*Vibrio cholerae* belongs to the family Aeromonadaceae (formerly Vibrionaceae). They are small Gram-negative rod-like facultative anaerobic bacteria and are also slightly curved in shape. A single polar flagellum gives them motility. *V. cholerae* is the aetiological agent for human cholera, a diarrhoea that can be fatal owing to the massive loss of water and electrolytes that it causes. *V. cholerae* colonizes the intestinal tract in extremely high numbers, releasing enterotoxins. After an incubation period of only around 30–45 min, diarrhoea, the major symptom, can be seen and as much as 1 l of water can be lost every hour.

*V. parahaemolyticus* is another Gram-negative species within the same family. It was thought that *V. parahaemolyticus* grew in curing brines. Despite the fact that *V. parahaemolyticus* is halophilic, thus requiring a salt-containing environment for growth, however, it does not grow in brines containing salt used to cure meat products. It also does not grow at temperatures below 5 °C. An infection caused by *V. parahaemolyticus* results in diarrhoea, abdominal cramps, vomiting, headache and fever. The incubation period is 6–72 h. The bacteria place themselves predominantly in the small intestine and excrete toxins which as yet have not been fully identified. The infective dose seems to be around 10<sup>6</sup> bacteria. These bacteria are more of a problem in seafood than in meat products.

*V. vulnificus*, however, another member of the family, can grow in curing brines. Therefore it should not be part of the microflora in a curing brine, especially in a 'live' brine used for the production of bacon or cured air-dried meat products. *V. vulnificus* is Gram negative and halophilic.

### 39.9.2 Genus *Aeromonas*

*Aeromonas hydrophila* is a Gram-negative non-spore-forming facultative anaerobic rod. Motility is due to a single polar flagellum. It can be found in

virtually all meat chillers but is responsible for only a small number of food-poisoning incidents. The gastroenteritis that it causes in immunocompromised people, however, can be severe. The incubation period is between 12 and 48 h and illness is caused by heat-labile enterotoxins. *A. hydrophila* grows at a wide range of temperatures and is able to grow at temperatures as low as 0 °C. The infective dose is not yet fully known. The organism is heat sensitive and proper pasteurization of meat products reaching 70 °C safely eliminates it.

## 39.10 Family Spirillaceae

### 39.10.1 Genus *Campylobacter*

*Campylobacter jejuni* is a cause of increasing concern in the food industry. It is a Gram negative, spirally curved, motile thermophilic rod, commonly present in poultry as well as beef and lamb. Motility originates from the corkscrew-like motion of a single polar flagellum. The bacterium is a facultative anaerobe and it is also microaerophilic, meaning that it needs reduced levels of O<sub>2</sub> to survive. Fastest growth is seen at O<sub>2</sub> levels of between 3% and 5% and CO<sub>2</sub> levels of between 2% and 10%. An A<sub>w</sub> of 0.97 is also required. *C. jejuni* can in addition live under anaerobic circumstances. Modified-atmosphere packing with a gas mix including CO<sub>2</sub> therefore does not kill it; as mentioned above, the presence of CO<sub>2</sub> is even preferred for growth.

Serious diarrhoea, fever and stomach ache are the main symptoms of food poisoning caused by *Campylobacter* spp. The incubation period is between 2 and 5 days and consumption of only a few hundred cells causes illness. Insufficiently thermally treated food, especially poultry, is frequently the reason for infection. The core of the meat should reach temperatures of 78–80 °C to eliminate safely this bacterium. *Campylobacter* spp. grow best at a temperature between 30 and 45 °C; so these temperatures should be avoided, especially if cooked food is reheated and kept warm.

## 39.11 Family Listeriaceae

### 39.11.1 Genus *Listeria*

*L. monocytogenes* is occasionally described as being a ‘genus of uncertain classification’. Most often, however, it is described as belonging to the family Listeriaceae and being closely related to the family Lactobacillaceae. *L. monocytogenes* is a ubiquitous small psychrotrophic Gram-positive non-spore-forming aerobic or facultative anaerobic catalase-positive rod-shaped bacterium which is found in chains of five or more cells. Motility is due to a characteristic tumbling movement caused by peritrichous flagella. *L. monocytogenes* prefers a pH range between 5.0 and 5.9 and a temperature

range 4–38 °C but it can withstand salt concentrations of 30% at 4 °C for a long period of time. It requires an  $A_w$  of above 0.92 for growth but can still grow at low temperatures (such as 1 °C) for long periods of time. A temperature below –2 °C, however, inhibits growth.

*L. monocytogenes* causes the foodborne disease listeriosis mainly in immunocompromised people and neonates. The infectious dose is above  $10^3$  per gram of food and the incubation period is between 1 and 50 days. Healthy humans with a fully functioning immune system, however, remain unaffected by counts as high as  $10^6$  per gram of food. *L. monocytogenes* is inactivated by cooking products up to 72 °C but packaging and slicing can cause recontamination. Most countries in the world permit a maximum level of *L. monocytogenes* of  $10^2$  per gram of food at the end of a product's shelf life while some other countries require *L. monocytogenes* to be 'negative in 25 g'. This is hard to maintain on a constant basis.

Parameters such as salt levels of 15% or a pH value of 4.1 stop growth of *L. monocytogenes* but these are impracticable in meat products. *L. monocytogenes* is particularly likely to cause illness in meat products such as undercooked frankfurters or bacon, which is only thermally treated to around 55–60 °C in the core. It is important, therefore, that the consumer cooks bacon properly to eliminate the risk of *L. monocytogenes*. Interestingly, in raw meat stored at 0–2 °C, *L. monocytogenes* does grow significantly as the competitive flora present, such as lactic acid bacteria, inhibit its growth. In a cooked and vacuum-packed meat product, such as a cooked sausage or cooked ham, in which the competitive flora are destroyed during thermal treatment, growth of *L. monocytogenes* occurs at a much faster rate. It is important to avoid post-cook contamination during slicing and packing of a meat product as lactic acid bacteria, acting as the competitive flora, grow only very slowly in packed products. The number of *L. monocytogenes* can increase to above  $10^4$  per gram easily within only 2 weeks. In vacuum-packed meat, growth of *L. monocytogenes* also depends on the pH of the meat itself and the storage temperature as well as on the presence of a competitive flora. On meat stored at a temperature below 7 °C at a pH below 5.7, no or little growth takes place, whereas at a pH above 6.0 (DFD meat), and the same storage temperature, *L. monocytogenes* grows rapidly. Bacteriocins such as sacacin can also help to inhibit the growth of *L. monocytogenes*.

### 39.12 Fungi in meat products

Fungi are eucaryotes and are larger in size than bacteria. They have a more developed cell structure than bacteria and their genetic material is separated from the cytoplasm by a nuclear membrane. The primary substance in the cell wall of true fungi is chitin. All fungi are chemoheterotrophic organisms which require carbon and organic substances for living. The study of fungi is known as mycology.

Fungi are classified primarily based on their method of reproduction, structure and life cycle. Members of the class Ascomycetes reproduce sexually via ascospores. Genera such as *Saccharomyces* and *Debaryomyces* in the family Saccharomycetaceae belong to this class. Yeasts are single-celled Ascomycetes. Members of the class Zygomycetes reproduce sexually via spores known as zygospores and asexually by the production of sporangiospores and the hyphae produced are non-septate (i.e. do not show cross-walls). Genera such as *Mucor* and *Rhizopus* belong to the family of Mucoraceae, which are part of the Zygomycetes class. Deuteromycetes, also known as Fungi imperfecti, reproduce asexually by the formation of conidia, which are externally produced spores. Genera such as *Penicillium*, *Aspergillus* and *Fusarium* are the most important in meat and meat products. They belong to the family Moniliaceae in the class Deuteromycetes. Figure 39.4 shows asexual spores of *Penicillium*, *Fusarium* and *Aspergillus*.

### 39.12.1 Yeasts

Yeasts are single-celled (unicellular) organisms. Yeast cells are larger than bacterial cells and vary dramatically in size from 2  $\mu\text{m}$  up to around 120  $\mu\text{m}$ . They are usually either spherical or oval in shape whilst some are rod shaped. *Saccharomyces* spp. and *Candida* spp. are oval-shaped yeasts. Most yeasts reproduce asexually by budding, but some yeasts reproduce sexually by forming spores. When yeast buds, the living parent microorganism seals off part of its cell and a bud then develops, which at the start is attached to the

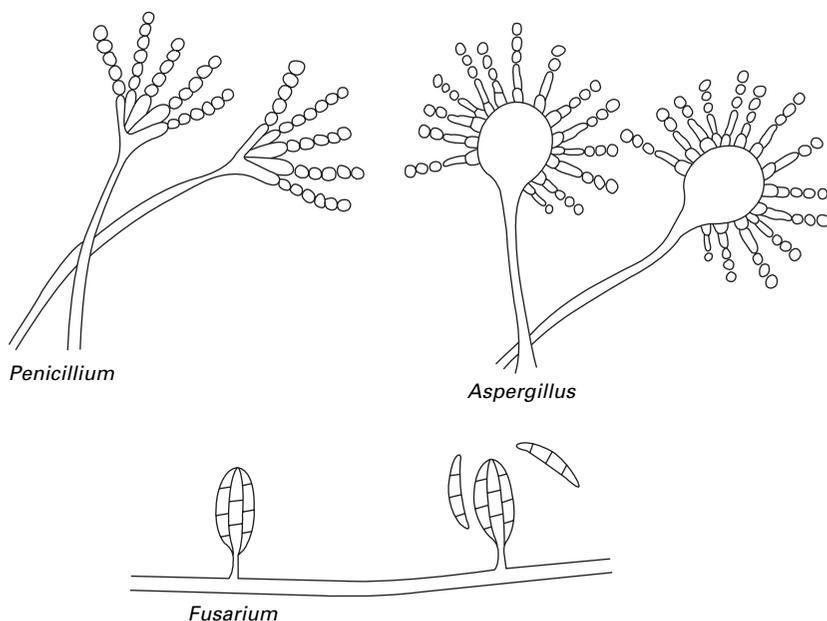


Fig. 39.4 Asexual spores of the genera *Penicillium*, *Fusarium* and *Aspergillus*.

parent's cell wall. The newly formed cells are either totally disconnected from the mother cell or can remain attached. If they do not disconnect, clusters of yeast form.

Yeasts require moisture in order to live and grow but can grow at lower  $A_w$  values than bacteria. Some species of yeast can live with very little water even at an  $A_w$  of 0.88. Yeasts prefer a pH range of 3.5–6 and a pH of around 4.5 (slightly acid) is optimal. The most favourable temperature for growth is around 25 °C and yeasts generally grow in a temperature range between 20 and 35 °C. Yeasts do not grow below freezing point but can survive temperatures as low as –10 °C. To survive, it is advantageous for yeasts if  $O_2$  is present, but they are facultative anaerobic. If no  $O_2$  is present, they ferment sugar into water and alcohol. On the other hand, if  $O_2$  is available, they break down sugar into  $CO_2$  and water. About five genera of yeasts are commonly found in meat and meat products. Species such as *Candida famata* and *Debaryomyces hansenii* are the most important and are occasionally used in the production of raw fermented salami.

### 39.12.2 Moulds

The term 'moulds' is used to refer to any mycelial fungus and Zygomycetes, Ascomycetes and Fungi imperfecti are classified as moulds. Moulds are complex multicellular microorganisms which generally reproduce by forming spores of various types. They reproduce both asexually and sexually and sometimes sexual and asexual reproduction are even found within the same species. The most common type of reproduction is asexual and involves spores called conidia. Conidia are asexual non-motile fungal spores, which are very light and are therefore spread around via airflow.

The structural units of moulds are thread-like strands called hyphae. When a mould grows, the part visible to the human eye is the mycelium, a structure made up of a large number of intertwined and branching hyphae. Moulds are generally aerobic and mesophilic (i.e. their optimum growth temperature is between 5 and 25 °C).  $O_2$  is vital for the formation of conidia and therefore the growth of mycelia. Most species of moulds have similar metabolisms to yeasts and require very little moisture in order to live. Therefore they are able to grow at low  $A_w$  values (i.e. they are xerophilic) and moisture from air normally fulfils their water requirements. They can also grow at temperatures below 0 °C. *Mucor* spp. require the highest level of humidity in order to grow whereas *Penicillium* spp. and *Aspergillus* spp. can grow with lower RHs. The optimum temperature for moulds to grow is around 25 °C although some species of moulds are able to grow at temperatures as low as –18 °C. The pH range required for growth is between 3.0 and 8.0 and most species of moulds prefer acid conditions, at a pH too low for optimum growth of bacteria and yeasts.

Fungi can produce mycotoxins as secondary metabolic by-products and these are toxic to humans at low concentrations. The production of mycotoxins

is specific to genera, species and even strains of fungi. Mycotoxins are generally produced at  $A_w$  values between 0.93 and 0.82. Reducing the storage temperature of meat products inhibits the formation of mycotoxins. Some types of mycotoxin are produced only 2 weeks after mould formation, whereas others, such as aflatoxins, are produced within the first week of growth of moulds. Mycotoxins are found to depths of around 0.5–0.8 cm under the surface of a meat product.

Formation of moulds can be prevented by applying substances such as smoke (containing phenolic materials), potassium sorbate, sodium propionate, natamycin (pimaricin) or garlic. Reducing water activity or vacuum packing to exclude  $O_2$  is also effective in preventing mould growth. Products such as salami or air-dried raw meat products can be dipped, or sprayed, with a solution of 10–15% potassium sorbate. The sorbate turns partly into sorbic acid, which penetrates slowly into the outer layer of the product and inhibits the growth of moulds. Propionate, the salt of propionic acid, also inhibits the growth of unwanted moulds. It is not very effective in fermented salami, however, because of the low pH (below 5.4) value of this product. At this low pH, propionate releases propionic acid which slowly evaporates. Some pastes seen on products such as pastirma (see Chapter 24, Section 24.7), contain up to 40% garlic and allicin, present in garlic, prevents growth of moulds. Drying rooms used to dry cured air-dried products operate at an RH around 70%, which, in conjunction with some air speed, prevents the growth of moulds. Table 39.2 shows the most common types of mould on meat and meat products and the toxins that they produce.

Species such *Aspergillus flavus*, *A. fumigatus* and *A. niger* are thought to use simple carbohydrates such as glucose, fructose and sucrose to produce aflatoxin B. This is a toxic compound which causes liver cancer in animals and may also cause liver cancer in humans. *Aspergillus* spp. also produce other mycotoxins such as B2, G1 and G2. *A. fumigatus* is predominantly the cause for the illness known as aspergillosis, but *A. flavus* and *A. niger* also cause this disease.

Ochratoxins, produced by members of the genus *Penicillium*, are responsible for kidney diseases in humans. *Fusarium culmorum*, on the other hand, produces trichothecenes such as T2, which damages the mucous membrane in the stomach, mouth and intestine, resulting in bleeding, diarrhoea and vomiting. *Aspergillus* spp. grow best at 20–30 °C whereas *Penicillium* spp. still grow at temperatures below 4°C. *Aspergillus* spp. also require a much

**Table 39.2** Common types of mould in meat and the toxins that they produce

Species	Type of toxin produced
<i>Aspergillus flavus</i>	Aflatoxin
<i>Penicillium viridicatum</i>	Ochratoxin
<i>Fusarium culorum</i>	Trichothecene

more selective range of nutrients for growth than *Penicillium* spp. Conversely, *Aspergillus* spp. can grow at lower  $A_w$  values than *Penicillium* spp. *Penicillium* spp. will grow only on raw air-dried products, such as Parma ham, if the surface is quite wet, whereas *Aspergillus* spp. will grow on products that have already been dried for a period of time. The growth of some strains of *Penicillium* on salami, however, is desirable and contributes to flavour development. An example of an important strain of *Penicillium* is *Penicillium nalgiovense*, which was the first cultivated non-toxic noble mould used on the surface of raw fermented salami. Growth of *Mucor* spp. is rapid under perfect conditions and this mould forms long beard-like micelles. Some strains are responsible for zygomycosis but, overall, infections caused by *Mucor* spp. are rare. *Mucor* spp. require more water to grow than *Penicillium* spp. or *Aspergillus* spp. Spoilage of food is occasionally due to black moulds. These moulds contain melanin in their mycelia, which is very resistant to UV light.

### **39.13 Bovine spongiform encephalopathy and other transmissible spongiform encephalopathies**

BSE, Creutzfeldt–Jakob disease (CJD), scrapie and kuru are all members of the family of diseases known as transmissible spongiform encephalopathies. The disease BSE (in animals) or CJD (in humans) is a chronic, progressive and fatal infection of the nervous system. The incubation period of these diseases (the period of time from infection until onset, or outbreak, of the actual illness) is extremely long and for BSE is between 4 and 6 years. Once BSE, or mad-cow disease, has broken out, it is fatal for cattle within a few months.

Scientists commonly accept that BSE and CJD are caused by prions, or ‘proteinaceous infectious particles’, which differ from known bacteria and viruses. Prions are hydrophobic pathogenic proteins and are predominantly made and found in the brain and other parts of the nervous system. In sheep, prions are also found in muscle tissue. Prions are extremely resistant to heat and acids as well as other chemical and physical impacts. They are also infectious. The protein has no DNA on its own and is defective in structure. The human immune system appears not to recognize it as an infectious agent and therefore there is no immune reaction against it. This enables the prion to replicate uncontrolled without being attacked. BSE and CJD cause tiny holes to form in the brain tissue, which ultimately ends up looking like a sponge. Up to now, these diseases are still not fully understood and no cures are available.

Digestion, which normally breaks down proteins, does not have an impact on prions. Therefore, when infected bone meal, which has not been properly heat treated, is fed to animals, the prions survive and can replicate. Some say that, to prevent the spread of BSE, cattle should not be fed cattle bonemeal.

On the other hand, however, bonemeal is a relatively cheap feed which is high in protein.

As prions are very heat resistant, carcasses of animals have to be treated at a minimum of 133 °C for 20 min under a pressure of 3 bar to denature all the protein structures safely and to prevent the development of prions. To control the spread of BSE, in most abattoirs worldwide today the spinal cord has to be removed from cattle during slaughter. In some countries, the entire backbone has to be removed from the carcass undamaged in order to guarantee that no nerve tissue from the spinal cord can contaminate muscle tissue. Beef brain is also no longer considered fit for human consumption.

Scrapie is a disease of sheep and goats, which causes symptoms similar to BSE. Scrapie is so called because of one of its symptoms; it causes the infected animal to rub against surfaces and to scrape off its hair or wool. As with BSE, the brain develops over time into a sponge-like material, which leads to death. Kuru used to be spread by the consumption of brain tissue from infected humans. It was found in places such as Papua New Guinea until ritualistic cannibalism ceased to be practised.

## 40

# Predictive microbiology for meat products

In predictive microbiology, the aim is to predict microbiological development in meat products and in particular to predict the growth of pathogens. Predicting microbial growth requires a database containing a large amount of information about the effects of the composition and processing of meat products on pathogen survival, growth and death. The database contains data on the effects of parameters such as pH,  $A_w$  and levels of salt and nitrite on pathogen behaviour. Based on these data and information about the composition of the food itself, the predicted growth of bacteria can be calculated. The parameters commonly considered in the mathematical model are the storage temperature of food, pH,  $A_w$  and levels of salt and nitrite. As many more parameters than this play a role in determining shelf life and microbial growth in meat and meat products, the results of predictive microbiology models are often designed to be very conservative. The situation in real life is often safer than the results the model suggests.

Validation of the results or, in other words, the comparison of calculated with actual results is also a major task. Some parameters cannot be factored into mathematical models, such as variations in storage temperature and in general a maximum of four hurdles can be considered at any one time in most models. Predictive microbiology therefore has its limitations.

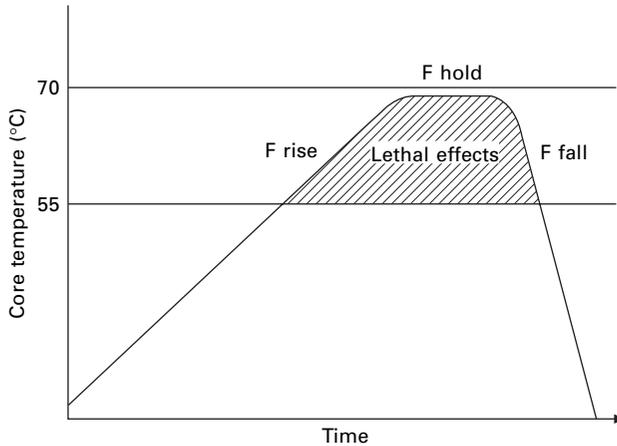
*F*-value calculations are also a form of predictive microbiology. An *F*-value calculation works out the conditions, or severity of heat treatment, required to destroy pathogens in meat products. Therefore, once an *F*-value has been calculated and achieved during thermal treatment the death, survival and growth of bacteria can be predicted.

## 40.1 *F*-value calculations and shelf life

The shelf life of meat products is an important topic and for purposes of distribution and storage a long shelf life is desired. The shelf life and safety of a food product nearly always depend on bacterial growth and therefore, to obtain a meat product with a long shelf life, it is highly beneficial to use raw materials with a low bacteria count. Severe heat treatment of meat products normally results in a low bacteria count in the finished product, but product quality can be affected. Textural qualities such as firmness can be badly affected by more severe heat treatment. In addition, heat treatment always involves using energy and, for that reason, has an impact on the manufacturing costs of the product. It must also be remembered that the heat resistance of bacteria in meat products during thermal processing is greatly influenced by the pH, water and fat content of the product and the concentrations of salt and nitrite present. Therefore meat products must be heat processed for different amounts of time and at different temperatures depending on their composition. Generally, a lower pH and/or a higher concentration of nitrite reduce the heat resistance of bacteria, thus inactivating them faster. On the other hand, a large amount of fat enhances heat resistance. A balance always has to be reached between product safety and product quality when manufacturing a meat product. With careful control of processing conditions, however, it is possible to optimize both. To optimize thermal processing, the lethal effect of heat on bacteria can be calculated as described below.

The *F* value (or thermal death time) is used as a basis for comparing heat pasteurization and sterilization procedures. It is the length of time in minutes for which a meat product must be exposed to a given temperature in its core to kill a certain number of microorganisms. The *F* value (also commonly known as the  $F_0$  value) is so called because 121.1 °C, the reference temperature used when calculating *F* values in retorted meat products, is equal to 250 °F. When calculating *F* values, a clear distinction is made between pasteurized and retorted (sterilized) products. The term 'cooked products' also refers to pasteurized products. Pasteurized products are those heat treated at around 74–82 °C until a core temperature around 68–72 °C is reached. Retorted products, on the other hand, are heated to temperatures between 112 and 121 °C.

It is important to remember that the total *F* value represents the total time–temperature combination that a food is subjected to when it is heat processed. In other words it is the sum of all lethal effects taking place as the core temperature increases (*F* rise), the desired core temperature is achieved and held (*F* hold), and the core temperature then decreases below the temperature where lethal effects are taking place (*F* fall). Figure 40.1 shows a curve which represents the core temperature in cooked ham under pasteurizing conditions. The lethal effect starts to take place at 55 °C and ends at the same temperature as the product cools. A temperature of 69 °C was obtained and maintained for a short period of time in the core of the product.



**Fig. 40.1** Lethal phase in the cooking of ham.

When bacteria are exposed to heat or heated in a moist environment at lethal temperatures, the same percentage die in a given time irrespective of the number of bacteria present initially. This is referred to as the logarithmic order of death. The general formula for calculation of the  $F$  value is

$$F = D \times (\log N_0 - \log N)$$

where  $D$  is the decimal reduction time i.e. the time required in relation to temperature to reduce the number of microorganisms by one logarithmic step, which is 90%.  $N_0$  is the bacterial count in a gram of the raw uncooked meat product and  $N$  is the maximum number of bacteria that can remain in the thermally treated product.

When calculating the  $F$  value in pasteurized products, the reference or target temperature is 70 °C and the lethal effect (i.e. the killing of bacteria) is said to start to occur from 55 °C upwards. In retorted products, the lethal effect is said to occur from 100 °C upwards and the reference temperature is 121.1 °C. In pasteurized products, the reference bacteria used are *D-Streptococcus*, which has a  $D_{70}$  value (i.e.  $D$  value at 70 °C) of 2.95 min, or 177 s. *D-Streptococcus* is not a pathogen but a food spoilage microorganism and is the most heat-resistant vegetative bacterium in pasteurized products. In retorted products the reference bacterium is commonly *Cl. sporogenes* as other more dangerous bacteria such as *Cl. botulinum* have a lower  $D_{121.1}$  value (i.e. a  $D$  value at 121.1 °C) than *Cl. sporogenes* and are therefore killed by less severe conditions. *Cl. sporogenes* has a  $D_{121.1}$  value (i.e. a  $D$  value at 121.1 °C) of 1 min whilst *Cl. botulinum* has a  $D_{121.1}$  value of 0.21 min.

The  $D$  values in the examples above (2.95 min, 1 min and 0.21 min respectively) indicate the times required for the bacteria to be reduced in number by one logarithmic step (e.g from  $10^5$  to  $10^4$  per gram of product), at the given temperature (e.g. 70 °C or 121.1 °C). The  $D$  value depends

greatly on temperature type of bacteria, and other factors such as pH. Each bacterium has a certain  $D$  value relating to a certain temperature. As an example, *D-Streptococcus* has a  $D_{70}$  value of 2.95 min but a  $D_{80}$  value (i.e. a  $D$  value at 80 °C) of 0.295 min. On the other hand, *D-Streptococcus* has a  $D_{60}$  value (i.e. a  $D$  value at 60°C) of 29.5 min. At all these different  $D$  values, relating to a certain temperature and a certain time, the same lethal effect (reduction in numbers by one logarithmic or  $D$  cycle) occurs. Because a  $D$  cycle reduces the number by 90%, a  $4D$  cycle would reduce the number by 99.99% (a  $2D$  cycle by 99%, and  $3D$  a cycle by 99.9%). Figure 40.2 illustrates the difference in pasteurization of a meat product at 70 or 75 °C. The  $D$  value at 75 °C is around three times lower than the  $D$  value at 70 °C. The lethal effect at 75 °C is thus greater by a factor of about 3. The time required to achieve the lethal effect at 75°C is therefore significantly reduced.

Because killing of bacteria follows a logarithmic scale, theoretically it is impossible to reduce the remaining risk, or residual bacteria count, to absolutely zero as the logarithm of zero is not defined in mathematical terms. As stated earlier,  $N_0$  is the bacteria count of a gram of the raw uncooked product and  $N$  is the number of bacteria that can remain in the thermally treated product. In retorted products,  $N$  can also represent the number of cans in which a bacterium could be found alive. In pasteurized products, it represents the number of microbiologically unstable products or the numbers of surviving bacteria per gram of food after thermal treatment. For example, if in a batch of retorted canned product the level of risk should be such that a bacterium only survives in one out of every 10000 cans,  $N$  equals  $10^{-4}$ . In pasteurized products, a statistical safety number  $N$  equal to  $10^{-5}$  is commonly used. More specifically, in pasteurized products, commonly the standard is that 1 in every 100000 pasteurized products could be microbiologically unstable.

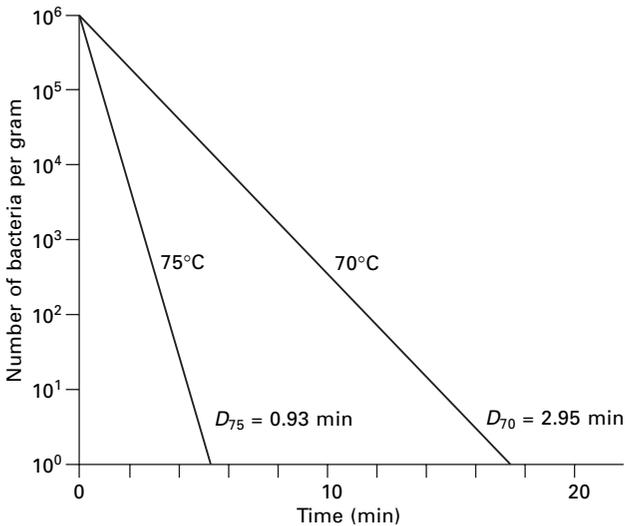


Fig. 40.2 Difference between the pasteurization of meat at 70 °C and at 75 °C.

To use the formula  $F = D (\log N_0 - \log N)$ , therefore, several values have to be known. These are, firstly the initial bacteria count ( $N_0$ ) per gram of meat product to be thermally treated, secondly the  $D$  value of the target bacteria, and thirdly the acceptable level ( $N$ ) of risk.  $N$ , as stated, can never be zero and, the lower  $N$  is supposed to be, the more severe the heat treatment and the greater the damage to product quality.

The process time, or the time for which a retorted or pasteurized product should be held at a certain processing temperature for the required thermal destruction to take place, also needs to be calculated. To achieve this, core temperatures measured in the product during thermal treatment have to be converted into time. This is done by calculating  $L$  values (lethal rates). The formula for the calculation of lethal rates in pasteurized or retorted products is

$$L = 10^{(T_1 - T_2)/z}$$

The same formula can be expressed as  $\log L = (T_1 - T_2)z^{-1}$ . In this formula,  $T_1$  is the core temperature measured within the thermally treated meat product whilst  $T_2$  is the reference temperature (70 °C for pasteurized products and 121.1 °C for retorted products). The  $L$  value is always calculated to a value of 1 (e.g.  $L_{70}$  for *D-Streptococcus* is 1, and  $L_{121.1}$  for *Cl. sporogenes* is 1). The  $z$  value is bacteria specific and is the difference, or increase, in temperature required (in °C) to reduce the  $D$  value by 90%, or to one tenth, of its original level. Expressed in another way, the  $z$  value is the rise in temperature required to increase the killing rate by 90%. The  $z$  value is the 'relative heat resistance' of a bacterium. At a  $z$  value of 10, or an increase in temperature of 10 °C, the sterilization effect is ten times greater. Some bacteria have a  $z$  value between 4 and 6 but in most cases they have a  $z$  value of 10.

The lethal rate in a pasteurized meat product equals 1 if the core temperature reached is 70 °C and this temperature (70 °C) is maintained for 1 min. The value of 1 is obtained by making  $T_1$  and  $T_2$  70 °C in the above formula. By dividing 0 (70–70) by 10 (the  $z$  value) the value of 0 is obtained and 10 to the power zero ( $10^0$ ) is 1. As a result, if a product is heated at 70 °C for 1 min a lethal rate of 1 is obtained, which equals an  $F_{70}$  value of 1 min.

On the other hand, if a temperature of, for example, 65 °C is measured during thermal processing in the core of a pasteurized meat product, the lethal rate is only 0.31, as  $T_1$  in the formula is 65 °C. By subtracting 70 ( $T_2$ ) from 65 ( $T_1$ ), the value of –5 is obtained. If this is divided by 10 (the  $z$  value), the value of –0.5 is the result ( $-5/10 = -0.5$ ). As the next step, 10 to the power of –0.5 ( $10^{-0.5}$ ) is 0.31. The value of 0.31 tells us that, if a temperature of 65 °C is obtained in the core of the meat product and held for 1 min, the lethal effect, or  $F$  value, at 65 °C for 1 min has the same killing effect on the target bacteria as 0.31 min at 70 °C. Those 0.31 min are equal to 18.6 s at 70 °C, which is the reference temperature (the value of 0.31 does not mean 31 s but 31% of 1 min, which is 18.6 s). In summary, the killing effect by having a core temperature of 65 °C for 1 min is only 31%, or roughly one third, of that having 70 °C in the core of a pasteurized meat product for 1 min.

In general, any temperature measured in the core of a product to be pasteurized between 55 and 69 °C results in an *L* value below 1 if put into the *L*-value formula in place of  $T_1$  for calculating lethal effects, or *F* values, in pasteurized products. At the same time, every core temperature measured above 70 °C results in an *L* value greater than 1. All *L* values when added up finally, as they express time in minutes, result in the total *F* value, which is also expressed in minutes.

Table 40.1 shows lethal rates in pasteurized products, based on a *z* value of 10 and with 70 °C as the reference temperature. The table shows clearly that the lethal effect of reaching a temperature of 70 °C in the core of the product and holding it for 1 min, equals 1 (with 70 °C as the reference temperature). If a temperature of 62 °C is reached in the core and held for 1 min, the lethal effect is 0.16 min based on 70 °C. On the other hand, if a temperature of 72 °C is reached in the core and held for 1 min, the lethal effect obtained is 1.58 min. The list also demonstrates the logarithmic order of death by looking at 60 °C, 70 °C and 80 °C, with the lethal effect increasing by tenfold between each temperature. The lethal effect for 1 min at 60 °C is only one tenth of that at 70 °C. However, a core temperature of 80 °C for 1 min results in ten times the lethal effect compared with a core temperature of 70 °C for the same period.

## 40.2 *F*-value calculations for pasteurized products

In pasteurized products, spoilage bacteria or spores have to be reduced to acceptable levels. However, spores are not destroyed completely as core temperatures above 100 °C are never reached. The reference bacterium is, as mentioned above, *D-Streptococcus*. Other vegetative pathogens such as *Salmonella* spp. and *Staphylococcus aureus* have a lower *D* value and are therefore killed before *D-Streptococcus* is eliminated. When the product to

**Table 40.1** Lethal effects at different temperatures in pasteurized meat (*F* value based on a reference temperatue of 70°C and a *z* value of 10)

Temperature (°C)	<i>F</i> <sub>10/70</sub> (min)	Temperature (°C)	<i>F</i> <sub>10/70</sub> (min)	Temperature (°C)	<i>F</i> <sub>10/70</sub> (min)
55	0.03	65	0.32	75	3.16
56	0.04	66	0.40	76	3.98
57	0.05	67	0.50	77	5.01
58	0.06	68	0.63	78	6.31
59	0.08	69	0.79	79	7.94
60	0.10	70	1.00	80	10.00
61	0.13	71	1.26	81	12.60
62	0.16	72	1.58	82	15.85
63	0.20	73	1.99	83	19.95
64	0.25	74	2.51	84	25.12

be pasteurized has a mass greater than 4000 g, the volume of the product has to be taken into account as well. This is because a considerably longer period of time is required for a temperature of 55 °C to be reached in the core and the first lethal effect to take place. In this case, the formula to be followed is

$$F = D \times [\log (y \times N_0) - \log N]$$

where  $y$  is the mass of the product in grams.

It is important to note that bacterial growth occurs to a small degree whilst the core temperature is in the range 6–55 °C. Nitrite inhibits excessive bacterial growth during this time. The action of nitrite is important as temperatures of around 35–45 °C are highly conducive to bacterial growth.

To illustrate the formula for larger products, let us take an uncooked ham with an initial bacterial count of  $10^5$  per gram and a weight of 5000 g. As a result of pasteurizing, a statistical safety level of  $10^{-5}$  should be established, which is equal to a 10 log reduction in the bacteria present in the ham. Therefore, the formula applied is

$$F_{70} = 2.95 [\log (5000 \times 10^5) \log 10^{-5}]$$

which produces

$$\begin{aligned} F_{70} &= 2.95 [8.70 - (-5)] \\ &= 2.95 \times 13.70 \end{aligned}$$

which produces

$$F_{70} = 40.4 \text{ minutes}$$

As seen, the heat treatment applied to the cooked ham has to take place in such a way that all the lethal effects add up to an  $F_{70}$  value of 40.4 min. In large ham products,  $F_{70}$  values above 50–60 are easily obtained by heating the product at around 76–80 °C to reach a core temperature around 70 °C. This is especially the case in large products such as ham on the bone. Entire pork legs are often pasteurized up to core temperatures of around 68–70 °C. In these products, thermal treatment results in  $F_{70}$  values of around 80–100. In cooked ham, around 75% of the total  $F$  value is reached during the rise in core temperature from 55 °C up to the desired core temperature ( $F$  rise) whilst the remaining lethal effects, or  $F$  values, are generally gained by maintaining the maximum core temperature for a while ( $F$  hold). The lethal effect obtained during the period of cooling ( $F$  fall), where the core temperature drops from its holding temperature to below 55 °C again, also contributes to the total  $F$  value, though only to a small degree.

There are no firm legal requirements or a minimum heat treatment for pasteurized products but  $F_{70}$  values of 40–60 and above are generally the norm. In practical terms, the core temperature of pasteurized products is checked during thermal treatment every 5–10 min and the temperature obtained is firstly converted into time in minutes using the  $L$ -value formula. The  $L$  value obtained relating to the measured temperature is then multiplied by the

number of minutes that have passed between each core-temperature check. For example, if the core temperature is checked every 10 min, the  $L$  value obtained for the temperature checked is multiplied by 10 to give the total  $L$  value for this period of 10 min. Fully integrated  $F$  value calculators connected to cooking chambers perform this kind of mathematical conversion and core temperatures can even be measured every single minute and converted into  $L$  values fully automatically. Entire cooking programmes are standardized this way to optimize parameters such as maximum core temperature and therefore to obtain a safe product with the required shelf life but also with the highest possible sensory quality.

In another example, the current pasteurizing regime of a cooked ham product results in an  $F_{70}$  value of 4 min below the calculated value. The maximum core temperature reached during pasteurization is 68 °C. As a result, the core temperature in the ham has to be held at 68 °C for another 6.4 min ( $4/0.63 \approx 6.35$ ) because at 68 °C the lethal effect compared with that at 70 °C (the reference temperature) is only 0.63 (see Table 40.1). The value of 0.63 can also be obtained by using the  $L$ -value formula ( $T_1 = 68$  °C  $T_2 = 70$  °C and  $z = 10$ ).

It is quite common for the reference temperature (70 °C) never to be reached during pasteurization as product quality could suffer as a result. Once core temperatures reach around 68 °C, this temperature is frequently maintained for around 20–30 min, depending on the product and desired total  $F$  value, before heat treatment is discontinued and the cooling phase commences. The combination of time and temperature results in  $L$  values which in turn add up to the total  $F$  value without ever needing to reach the reference temperature. However, this does not mean that the reference temperature cannot or should not be reached on occasion. In some pasteurized meat products it is quite common that core temperatures of 71–72 °C are obtained to denature myoglobin and haemoglobin fully.

Table 40.2 shows as an example a cooked ham, which is pasteurized at a constant temperature within the cooking chamber at 78 °C. The core temperature is checked every 10 min and the lethal effect starts to take place from 55 °C upwards. Measured core temperatures are converted into time in minutes by using the  $L$ -value formula. This example demonstrates that the total  $F_{70}$  value obtained during thermal treatment for 220 min (in which the core temperature rose from 55 to 70 °C and then decreased during cooling again to below 55 °C) resulted in total lethal effects of 55.3 min. Therefore, the  $F_{70}$  value for this product is 55.3, which demonstrates an effective cooking process that provides a satisfactory safety and shelf life. Higher  $F$  values extend the shelf life further but at the same time have a damaging effect on the product quality. It is important to note that 220 min (which equals around 3.5 h) is not the total cooking time of this ham product. 220 min is just the period of time in which the core temperature varied between 55 and 70 °C and lethal effects took place. The time taken to reach the core temperature of 70 °C from a temperature of 55 °C took 160 min (almost 3 h). The total

**Table 40.2** Theoretical example of lethal effects in cooked ham at different temperatures

Temperature (°C)	Time (min)	Lethal effect per minute	Lethal effect for 10 min
55	10	0.03	0.30
56	20	0.04	0.40
57	30	0.05	0.50
58	40	0.06	0.60
59	50	0.08	0.80
60	60	0.10	1.00
61	70	0.13	1.30
62	80	0.16	1.60
63	90	0.20	2.00
64	100	0.25	2.50
65	110	0.32	3.20
66	120	0.40	4.00
67	130	0.50	5.00
68	140	0.63	6.30
69	150	0.79	7.90
70	160	1.00	10.00
65	170	0.32	3.20
63	180	0.20	2.00
61	190	0.13	1.30
58	200	0.06	0.60
57	210	0.05	0.50
55	220	0.03	0.30
Total			55.30

cooking time, therefore, could have been around 4.5–5 h because a fairly long time is required for the core temperature of a ham to rise from around 5–8 °C after filling to 55 °C.

Cooked ham is also produced in cans. Core temperatures of 66–70°C are reached when thermally treating these products but they have to be stored below 5 °C as the mild heat treatment does not render spores inactive. Some vegetative pathogens, such as *Salmonella* spp. and *Staph. aureus*, may also have survived.

### 40.3 *F*-value calculations for retorted products

In retorted products, the same principles apply as in pasteurized products with just a few differences. As stated earlier, the reference temperature in retorted products is 121.1 °C and the reference bacterium is *Cl. sporogenes*, which has a  $D_{121.1}$  value of 1 min. Lethal effects start to take place from 100 °C upwards. The *L* values, or lethal effects, are calculated using the above *L* value formula ( $T_1$  is the measured core temperature in the retorted products and  $T_2$  is 121.1 °C). The *z* value is most often 10 as well. As in the case of pasteurized products, different temperatures result in different *D*

values. *Cl. sporogenes* has a  $D_{111.1}$  of 10 min and a  $D_{131.1}$  of 0.1 min. Bacterial death follows a logarithmic scale; the same lethal effect is achieved by obtaining a core temperature of 111.1 °C for 10 min as having 121.1 °C (reference temperature) for 1 min. On the other hand, a core temperature of 131.1 °C for 1 min has an impact ten times greater than a core temperature of 121.1 °C for 1 min.

Table 40.3 displays different  $L$  values in retorted products calculated at 121.1 °C taking a  $z$  value of 10. The reference temperature of retorted products, 121.1 °C, is most commonly never reached as a core temperature during the retorting process, because product quality would suffer too greatly. Core temperatures between 115 and 117 °C are frequently used instead. Converting measured core temperatures into time in minutes to calculate the lethal effect allows maintenance of temperatures slightly below the reference temperature in combination with an increased time of heat treatment. As such, the combination of time and temperature provides  $L$  values which in turn add up to the total  $F$  value required even when the reference temperature is never reached.

**Table 40.3** Different  $L$  values in retorted products ( $F$  value based on a reference temperature of 121.1 °C and a  $z$  value of 10)

Temperature (°C)	$F_{10/121.1}$ (min)
101.1	0.01
111.1	0.10
121.1	1.00
131.1	10.00

The major danger in retorted meat products is *Cl. botulinum* which is safely eliminated by achieving an  $F_{121.1}$  value of 2.52 min. This  $F$  value is also known as the ‘botulinum cook’ and, for safety reasons, 3 min is the commonly applied  $F_{121.1}$  value for *Cl. botulinum*. The same lethal effect can be achieved by obtaining an  $F_{111.1}$  value of 30 min. All lethal effects obtained during the retorting process (including the effects obtained when the core of the product is below the holding temperature, when the core is at holding temperature, and when the product cools) must add up to at least 2.52 min to destroy *Cl. botulinum* and its spores safely.

The botulinum cook is based on the 12D concept. The impact of heat during the retorting process must be so severe that the number of *Cl. botulinum* is reduced by 12 logarithmic steps (99.9999999999%). The number of *Cl. botulinum* in a meat product is never  $10^{12}$  per gram but this high ‘theoretical’ percentage reduction in numbers is required as *Cl. botulinum* presents a very serious microbiological risk. The bacterium has a  $D_{121.1}$  value of 0.21 min. The formula applied for the botulinum cook is

$$F = D (\log N_0 - \log N),$$

which produces

$$\begin{aligned} F &= 0.21 \times (\log 1 - \log 10^{-12}) \\ &= 0.21 \times 12 \end{aligned}$$

which produces

$$F_{121.1} = 2.52 \text{ min}$$

A time of 2.52 min is sufficient to reduce the risk that a spore of *Cl. botulinum* survives in one of every  $10^{12}$  cans. As mentioned above, 3 min is the commonly applied  $F_{121.1}$  value for *Cl. botulinum* in retorted products.

Some bacteria have a higher  $D_{121.1}$  value than *Cl. botulinum*. As a result a longer heat treatment is required to lower the bacteria count by one logarithmic step. *Bacillus stearothermophilus* is the most heat-resistant bacterium with a  $D_{121.1}$  value of 4.8 min.  $F_{121.1}$  values of 12–16 min are used in case the finished product is stored at high temperatures, e.g. in tropical countries, for long periods of time (years). So-called three-quarter cans are produced, which contain three-quarter-preserved meats and have an  $F_{121.1}$  value of 0.7–0.9 min. The presence of nitrite inhibits spores from germination in such products and they must be stored in conditions below 10 °C for no longer than 8–12 months. Otherwise, surviving spores of *Bacillus* spp. or *Clostridium* spp. could germinate. This is because mild retorting does not safely eliminate all spores. Quite commonly, three-quarter cans are stored refrigerated at or below 4 °C.

Fully retorted meat products have an  $F_{121.1}$  value between 5.0 and 7.0 min and can be stored at ambient temperatures (around 20 °C) for up to 2–3 years. However, even heat treatment this severe is insufficient for products to be stored under tropical conditions for 2 years or even longer. Those products generally have an  $F_{121.1}$  value between 12 and 16 to destroy thermophilic spore-forming bacteria and their spores fully.

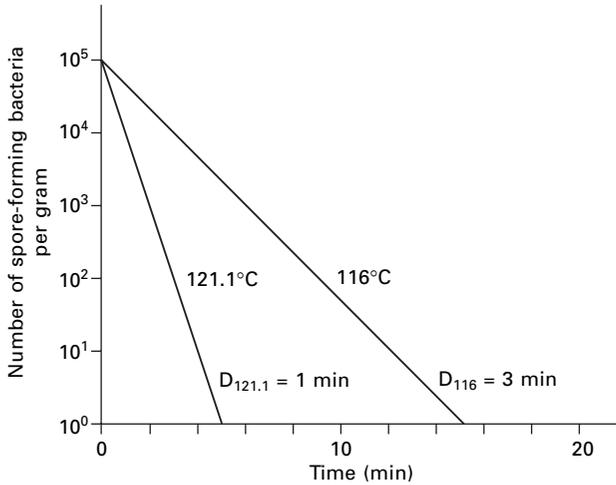
As an example, an uncooked sausage mass to be retorted exhibits a bacteria count  $N_0$  of 100 000, or  $10^5$ , per gram. The risk threshold of a surviving bacterium or spore is set at one in every 10 000 cans, which equals a risk  $N$  of  $10^{-4}$ . The reference bacterium when retorting meat products is *Cl. sporogenes* which has a  $D_{121.1}$  value of 1. The formula therefore would be

$$\begin{aligned} F &= 1(\log 10^5 - \log 10^{-4}) \\ &= 1 [5 - (-4)] \\ &= 1 \times 9 \end{aligned}$$

which produces

$$F_{121.1} = 9 \text{ min}$$

Therefore, all lethal effects in the core of the product above 100 °C in the retorting process (including holding and cooling time) must add up to 9 min in total. A temperature of 121.1 °C has been taken as the basis for the  $L$ -value



**Fig. 40.3** Time required to reduce bacterial numbers from  $10^5$  to  $10^0$  at 116 °C and 121 °C.

calculation. This is also well above the botulinum cook given that a time of 2.52 (or 3) min is required to safely eliminate *C. botulinum*.

Assuming that the retorting process currently used for the uncooked sausage in the example above adds up to an  $F_{121.1}$  value of only 7 min (therefore 2 min are missing) and the maximum core temperature applied is 116 °C, the temperature of 116 °C would have to be maintained for 6.5 min longer to equal a lethal effect comparable with that achieved by retorting for 2 min longer at 121.1 °C. By using 116 °C as  $T_1$  and 121.1 °C as  $T_2$  in the  $L$ -value formula, the value of  $-5.1$  is obtained ( $116 - 121.1 = -5.1$ ). This value in turn is divided by 10 ( $z$  value) resulting in  $-0.51$ . As the last step,  $10^{-0.51}$  results in an  $L$  value of 0.31. By dividing the missing 2 min by 0.31 the value of 6.5 is obtained. This means, as explained above, that the core temperature has to be held for 6.5 min longer at 116 °C in order to achieve the same lethal effect as created by holding the core temperature for 2 min longer at 121.1 °C. Figure 40.3 shows the time required to reduce the number of bacteria from  $10^5$  to  $10^0$  at 116 °C and at 121 °C.



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