**Post-harvest Physiology and Technology of Horticultural Crops**



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**CHAPTER ONE**

1. **Introduction**

**Chapter learning objectives**

At the end of this chapter students should be able to:

* Define what postharvest physiology and technology is
* Recognize basic concepts of postharvest physiology
* Differentiate the relationship between horticultural crops & postharvest physiology
* Realize the significance of post-harvest losses
* Define postharvest loss
* Estimate extent of postharvest loss of perishables
* Discuss the importance of postharvest loss
* Realize the natures and causes of post-harvest losses
* Point out/illustrate the major causes of postharvest loss
* List and discuss the means of prevention and control measures

**Content**

* 1. Basic concept of post-harvest physiology
	2. Importance of perishables
	3. Definition of post-harvest physiology and technology
	4. Postharvest nature of horticultural crops
	5. Importance of postharvest physiology
	6. Definition of post-harvest loss
	7. Extent and types of post-harvest losses
	8. Importance of postharvest losses
	9. Causes of postharvest losses

## Basic concept of post-harvest physiology

After spending months or years working in the field and harvesting the produce, everybody wants to ensure that the customers will enjoy this healthy harvest. The basic question in this intention is **how the quality and safety of the produce could be maintained during the time from harvest up to consumption**. High quality and disease free produce with a good shelf life is the result of sound production practices, proper handling during harvest and appropriate post-harvest handling and storage. Generally post-harvest handling maintains the produce through the time of harvest to the ultimate utilization, deterioration and death of the produce.

The way of utilization is not the same for all crops. For instance cut flowers are utilized as decoration whereas food crops are used for actual consumption. Different crops have also different resistance of loss in their shelf life; these are affected by the physiology of the produce. Pre-harvest factors have also an effect on post-harvest physiology. Environmental factors such as soil type, temperature, frost and rainy weather at harvest can have an adverse effect on storage life and quality of the produce.

Unsatisfactory management practices during production like watering, fertilization, control of pests and disease, and occurrence of mechanical injuries could be considered as pre-harvest factors in post-harvest physiology. Generally, understanding the post-harvest physiology and technology is very important for reduction of post-harvest losses (as these are wastage of produce, labor, material and capital).

**1.2 Importance of perishables**

Activitey 1.1. What is importance of horticultural crops?

Activity 1.2. Why do we grow and consume fruit and vegetables?

1. **Nutritional importance**

Activity 1.3. What are phytochemicals and what are their roles in human diet?

* Fresh fruits & vegetables have been part of human diet for long time
* In the early days, animal products were more valued and only few nations capitalized on fruits and vegetables
* However, recently more attention has been rendered to the later because of more Obesity and coronary heart diseases incidences
* Estimates for the year 2006 are that 80,000,000 people in the United States have one or more forms of cardiovascular disease (CVD).
* Nearly 151,000 Americans killed by CVD in 2005 were under age 65.

Fruits and vegetables are low in fat and high in dietary fiber thus they are good substitute for animal based food staffs.

* As for ornamentals
	+ Mixed with prepared foods
	+ Principally, they are food for the mind
	+ Traditionally, they are gown in gardens, interiorscapes, hotels and offices
	+ Especial occasions
		- Weddings
		- Funerals
		- Mothers’ day
		- Valentine’s day
		- Parades and rallies
		- In some countries, they are symbol of the state

**ii. Economic importance:-** World population gets food resources from grains and cereals (52%), fruits and vegetables (41%), and animal products (7%). About 1.12 billion tons of horticultural crops (roots and tubers, vegetables and fruits) are produced all over the world every year and serve as source of income, creating job opportunity etc.

**iii. Aesthetic appeal: -** fruits and vegetables have excellent aroma, flavour and colour, that helps it to have excellent aesthetic appeal.

Activity 1.4. Define postharvest *physiology*

* 1. **Definition of post-harvest physiology and technology**

**Postharvest physiology**- It is the division of plant physiology dealing with **functional processes** in plant material after it has been harvested. It is concerned with plants or plant parts that are handled and marketed in the living state including seeds, fruits, vegetables, cut flowers and foliage nursery products, etc. It is the study that involves maintaining quality and preventing spoilage of horticultural crops. The postharvest physiology deals with the time period from harvesting or removal of the plant from its normal growing environment to the time of ultimate utilization, deterioration or death. In a situation where pre-harvest and harvesting factors have a direct influence on postharvest response, they are also considered to be vital components of the complete postharvest picture.

* 1. **Post-harvest nature of Horticultural crops**

Activity 1.5. Make a distinction between durable & perishable plant products (Discuss in group).

**Durables**

* + Low moisture (10-15%)
	+ Small unit size (<1kg)
	+ Very low respiration rate with very small heat generation
	+ Hard texture, not easily damaged
	+ Stable, natural shelf life of several years
	+ Loss mainly caused by external agents, e.g. Molds, insect & rodents

**Perishables**

* + High moisture (50-90%)
	+ Large unit size (5g-5kg or more)
	+ High to very high respiration rate, with high heat production
	+ Soft texture, easily damaged
	+ Perishable, natural shelf life few days at best several months
	+ Loss caused partly by external agents e.g. rotting, bacteria & fungi and partly by endogenous factors, respiration, senescence and sprouting
	1. **Importance of post-harvest physiology and handling of perishable products**

Activity 1.6. Why the study of postharvest physiology & technology of horticultural crops is so important?

When we harvest wheat or teff, little harm is done. While in vegetables, fruits and ornamentals the damage is painful. In human terms it is “murder” (Ramswamy, 2005). So harvesting marks the beginning of deterioration process. Understanding postharvest physiology has advantages in increasing food supply and improving the economic situation of the producers and the country. Some of the importance of knowing post-harvest physiology & technology are the following:

* Horticultural products are usually of high value (compared to grains) and need to be handled carefully in order to preserve that value.
* Horticultural products are living commodities even after they have been harvested and deteriorate in quality very quickly. Therefore, it needs to maintain their quality in terms of appearance, texture, flavor and nutritional value etc…
* A lot of money and other resources are invested in growing the crop, and to get the best price possible for the crop, it must be looked after appropriately until it reaches the consumer.
* Horticultural crops are rich source of vitamins, minerals, proteins and medicinal substances proper care helps maintain nutritional & pharmacological value.
* Quantity and quality of food supply will be maintained.
* Reducing post-harvest loss has economical advantage. Remind that post-harvest handling uses only <1% of the energy used in production.
* Respiration and other metabolic activities takes place even after harvest, hence there should be substrates for such respiration;
* Water is the major constituent, hence easily perishable or having short shelf life;
* Fresh produce are used in a state which require careful handling to maintain its food safety from harvesting to ultimate use. Hence mechanical injury and contamination with harmful, dust or any other extraneous materials should be avoided in order to have good quality and healthy produce for consumers;

**1.6 Definition of post-harvest loss**

Activity 1.7. What is Post-harvest loss?

Activity 1.8. When do we say a given perishable crop is lost?

A **post-harvest loss** is any change in the quantity or quality of a product after harvest that prevents or alters its intended use or decreases its value. Losses can be qualitative or quantitative. The extent of loss in perishables depends upon type of commodity (5-100 percent).

Activity 1.9. Where is the beginning of postharvest loss?

Losses can occur at any stage after harvest

* Culling after harvest
* Grading (field or packing house)
* Storage loss
* Transit loss
* Retail loss
* Consumer loss



**The best quality goes to the market!!! The poor quality goes to waste and some part to secondary market!!!s**

Figure 2.1.Graphic representation of the food pipeline by Bourne (1977)

**1.7. Extent of post-harvest losses**

Activity 1.7. How big is the extent of post-harvest loss?

Activity 1.8. How do you think postharvest losses vary across commodity types, with production areas and the season of production?

Generally, Post-harvest losses vary greatly across **commodity types**, **with production areas** and the **season of production**.

1. **The nature of the product/its perishability**

In nature, horticultural products are more perishable that agronomic products. This is due to the fundamental differences between perishables/horticultural crops/ and durables /agronomic crops/. Generally postharvest loss is expected to be 25% and 25–100% for durables and perishables, respectively. There is also a difference among horticultural crops in terms of postharvest period losses. Fruits and vegetables are more perishable than root and tuber crops.

Table 2.1. Reported losses in less developed countries on different horticultural commodities, production amount & estimated loss

|  |  |  |  |
| --- | --- | --- | --- |
| **No**  | **Commodities**  | **Production (000 tone)**  | **Estimate loss (%)** |
| 1 | **Root and tuber crops** |  |  |
| Carrot  | 557 | 44 |
| Potato  | 26,909 | 5 – 40 |
| Sweet potato  | 17,630 | 35 – 95 |
| Yams | 20,000 | 10 – 60 |
| Cassava  | 130,486 | 10 – 25 |
| 2 | **Vegetables**  |  |  |
| Onion  | 6,474 | 16 – 35  |
| Tomatoes  | 12,755 | 5 – 50  |
| Plantain  | 18,301 | 35 – 100  |
| Cabbage  | 3,036 | 37 |
| Cauliflower  | 916 | 48 |
| Lettuce  | - | 62 |
| 3 | **Fruits**  |  |  |
| Banana  | 36,898 | 20 – 80  |
| Papaya  | 931 | 40 – 100  |
| Avocado | 1,020 | 43 |
| Citrus  | 22,040 | 20 – 95  |
| Grape  | 12,720 | 27 |

1. **Production area**

The amount of postharvest loss is different in developed (5 - 25%) and less developed (20 – 50%) countries. The pattern of loss is also different in the two classes of the world. When compared to postharvest loss, high loss is occur on the farm during harvest in developed countries due to; mechanical damage by machine harvesters and rejection of the product (only by considering their size, shape and color on the field without looking its quality or content). On the other hand, harvest losses on the farm are low in less developed countries because of; less mechanical damage/harvest is done by hand picking/ and low quality standards. However, postharvest losses are high in these countries because of the very poor postharvest technology. Generally, the magnitude and pattern of loss varies among developed and less developed countries because of the variation in economic and technological situations. Overall, about one third of horticultural crops produced are never consumed by humans. Overall, about one third of horticultural crops produced are never consumed by humans.

The extent of loss in perishables depends upon type of commodity 5-100%. Post-harvest losses in developed countries are much less as compared to developing countries.

* In Ethiopia, some perishables have shown up to **80%** loss
* Loss of product = much more than just the cost of the commodity

### 1.8. Types of post-harvest losses

The types of postharvest loss could be:

* **Quantitative loss:-** complete physical loss or loss of weight or volume
* **Qualitative loss:-** loss of nutritional value, sensory/change in aroma, flavour, color, texture and freshness
* **Economic/marketability loss**

### Activity 1.9.What is the role of internal and external quality attributes?

**1.9 Causes of post-harvest losses**

Factors affecting post-harvest food losses of perishables vary widely from place to place and become more and more complex as systems of marketing become more complex. A farmer who is growing fruit for his family's consumption probably doesn't mind if his produce has a few blemishes and bruises. If he is producing for a market at any distance from his own locality, however, he and his workers, if he has any, must have a different attitude if he hopes to get the best money return on his work. All fruits, vegetables and root crops are living plant parts containing 65 to 95 percent water, and they continue their living processes after harvest.

Their post-harvest life depends on the rate at which they use up their stored food reserves and their rate of water loss. When food and water reserves are exhausted, the produce dies and decays. Anything that increases the rate of this process may make the produce inedible before it can be used. The principal causes of loss are discussed below.

The grower must recognize that small changes in attitudes toward the prevention of post-harvest food losses may profit him more than changes in the techniques of the marketing chain, whether containers or transport improvements, and may cost him less in the long run. He must instruct his family, field workers, and others in the methods of reducing his losses.

Activity 1.10. What are the major causes of loss after harvest?

**Bourne (1977); Salunke and Desai (1989) have classified the causes of loss as follows:**

1. **Primary Causes of Loss**

Primary causes of losses are those causes that directly affect the food. They may be classified into the following groups:

1. **Biological:** Consumption of food by rodents, birds, monkeys and other large animals causes direct disappearance of food. Sometimes the level of contamination of food by the excreta, hair and feathers of animals and birds is so high that the food is condemned for human consumption. Insects cause both weight losses through consumption of the food and quality losses because of their webbing, excreta, heating, and unpleasant odors that they can impart to food.
2. **Microbiological:** Damage to stored foods by fungi and bacteria. Micro-organisms usually directly consume small amount of the food but they damage the food to the point that it becomes unacceptable because of rotting or other defects. Toxic substances elaborated by molds (known as mycotoxins), cause some food to be condemned and hence lost. The best known of the mycotoxins is aflatoxin (a liver carcinogen), which is produced by the mold Aspergillusflavus.

Another mycotoxin which is found in some processed apple and pear products is patulin, which is formed in the apple by rotting organisms such as *Penicilliumexpansum* which infect fresh apples before they are processed.

All living material is subject to attack by parasites. Fresh produce can become infected before or after harvest by diseases widespread in the air, soil and water. Some diseases are able to penetrate the unbroken skin of produce; others require an injury in order to cause infection. Damage so produced is probably the major cause of loss of fresh produce. The influences of all three causes are strongly affected by the various stages of post-harvest operations. Furthermore, they all have great effect on the marketability of the produce and the price paid for it.

1. **Chemical:** Many of the chemical constituents naturally present in stored foods spontaneously react causing loses of color, flavor, texture and nutritional value. An example is the Maillard reaction that causes browning and discoloration in dried fruits and other product. There can also be accidental or deliberate contamination of food with harmful chemicals such as pesticides or obnoxious chemicals such as lubricating oil.
2. **Biochemical reactions:** A number of enzyme-activated reactions can occur in foods in storage giving rise to off-flavors, discoloration and softening. One example of this problem is the unpleasant flavor that develops in frozen vegetables that have not been blanched to inactivate these enzymes before freezing.
3. **Mechanical:** Bruising, cutting excessive pulling or trimming of horticultural products are causes of loss. Careless handling of fresh produce causes internal bruising, which results in abnormal physiological damage or splitting and skin breaks, thus rapidly increasing water loss and the rate of normal physiological breakdown. Skin breaks also provide sites for infection by disease organisms causing decay.
4. **Physical:** Excessive or insufficient heat or cold can spoil foods. Improper atmosphere in closely confined storage at times causes losses.
5. **Physiological:** Natural respiratory losses which occur in all living organisms account for a significant level of weight loss and moreover, the process generates heat. Changes which occur during ripening, senescence, including wilting, and termination of dormancy (e.g., sprouting) may increase the susceptibility of the commodity to mechanical damage or infection by pathogens. A reduction in nutritional level and consumer acceptance may also arise with these changes. Production of ethylene results in premature ripening of certain crops. An increase in the rate of loss because of normal physiological changes is caused by conditions that increase the rate of natural deterioration, such as high temperature, low atmospheric humidity and physical injury. Abnormal physiological deterioration occurs when fresh produce is subjected to extremes of temperature, of atmospheric modification or of contamination. This may cause unpalatable flavours, failure to ripen or other changes in the living processes of the produce, making it unfit for use.
6. **Psychological:** Human aversion, such as "I don't fancy eating that today". In some cases food will not be eaten because of religious taboos.

**Microbiological, mechanical and physiological** factors cause most of the losses in perishable crops.

1. **Secondary Causes of Loss**

These are losses that lead to conditions that encourage a primary cause of loss. They are usually the result of inadequate or non-assistant capital expenditures, technology and quality control. Some examples are:

* Inadequate harvesting, packaging and handling skills.
* Lack of adequate containers for the transport and handling of perishables.
* Storage facilities inadequate to protect the food.
* Transportation inadequate to move the food to market before it spoils.
* Inadequate drying equipment or poor drying season.

Traditional processing and marketing systems can be responsible for high losses.

Table 1.1 Main causes of post-harvest losses in vegetables



Activity 1.11.How do we minimize these losses?

* **There is a huge loss! What can be done?**
* **Grow more food or reduce postharvest loss?**
* **How much more food?**

World population is increasing at faster rate than food production. Population growth: 50% increase in 20 years. Food production: increases by 3-5% per 5 years. However, with increasing population and limited land, this option has proved impossible. Employing modern agricultural operations was also less applicable to developing countries.

Another practical alternative is to minimize post-harvest losses to increase food availability. Grow **More Food & reduce post-harvest losses**. Although minimizing post-harvest losses of already produced food is more sustainable than increasing production to compensate for these losses, less than 5 percent of the funding of agricultural research and extension programs worldwide is devoted to activities related to maintenance of produce quality and safety during post-harvest handling. This situation must be changed if success is to be achieved in reducing post-harvest losses of horticultural perishables.

**How do we grow more food?**

* + Cultivate more land
	+ **Intensify** agricultural production
	+ Use high density planting
	+ Use modern tools
	+ Use growth promoters
	+ Use new varieties, new fertilizers
	+ Use **genetically modified** foods??
	+ We should do EVERYTHING we can

**PLUS, more importantly reduce post-harvest losses**

**Farmer must give careful attention to:**

* Market demand for the products he will grow; he must know the market and his buyers.
* Cultivation: Follow Good Agricultural Practices (GAP)
* Suitable and attractive packing or packaging.
* Transportation in refrigerated van
* Market handling; possibly storage or refrigeration.
* Perishability of the produce.
* Appropriate post-harvest processes (harvesting, cleaning, grading, cooling, storing, packaging, transporting and marketing).

 **Advantages of reducing PHL**

* Nutritional advantages
* Economic Advantages
* Feedback incentive to the growers
* Cost effective
* Environmentally friendly
* Consumer satisfaction
* How can we reduce post-harvest losses?

 **How can we reduce post-harvest losses?**

 **We can do it if we**

* 1. Understand the causes of postharvest losses
	2. Determine factors which affect them and how
	3. Effectively use conditions which control the factors and minimize the spoilage
	4. Understanding the nature of the produce
	5. Design an appropriate handling techniques that maintain the produce in best condition

**Review questions**

1. Specify the distinguishing features of pre-harvest, postharvest physiology and technology.
2. Give explanation on how ornamentals plants are said to be **food for the mind**.
3. What is the need of studying about perishables after harvest?
4. Quality products are produced in the field. But, the quality of a product is maintained during its harvest and post-harvest management. What do you understand from this sentence?
5. What are the negative consequences of inappropriate post-harvest handling? Illustrate clearly in detail.
6. Why do we need to cool horticultural produce as soon as possible after harvest

**CHAPTER TWO**

**2.Structure and Composition of horticultural crops**

**Chapter learning objectives**

**At** the end of this section students will be able to:

* Recognize the importance of fruits and vegetables
* Understand the structure and chemical composition of harvested materials

**Content**

* 1. Structure of harvested material
	2. Chemical composition

## 2.1. Structure of the harvested product

Activity 2.1. What is the significance of know the structure of harvested products in relation to their postharvest physiology?

The physiological changes that take place on harvested products and the way to handle the products depends on the material harvested. The above two are related with the structure of the product which in turn related with the function, because there is specialization in the intact plant. Based on structure, horticultural products are categorized as leaves, stems, flowers, fruits, and below ground structures (roots, bulbs and tubers).

1. **Leaves**

Harvested leaves of vegetables like spinach, cabbage, lettuce, celery, leek, and onion widely used as food. When the leaves are on intact plant, they play important role in carbon fixation (photosynthesis) and transpiration (control loss of water and heat removal).

At harvest, carbon fixation and transpiration stopped, stomata closed and the continued survival of the leaf depends on the energy and water already present in the leaf. Leaves of most species do not act as long term reserves because of rapid respiration and water loss; leaf area is large and the harvested material is exposed to sunlight and water easily evaporate which lead to rapid deterioration of the products quality.

1. **Stems**

Some vegetables like asparagus (sprouted stem), Brussels (auxiliary buds) and Sugar cane (true stem) have edible stems and these stems are young tissues, metabolically active and it has continued development after harvest.

1. **Flowers**

Flowers are composed of compressed shoots that are adapted for reproduction. Plant breeders have produced various vegetables with dense massed flower heads that can be eaten when the flowers are immature buds. These have long been popular in temperate countries but in recent years have become well-known in the tropics, where cultivars that can be grown in warm conditions or at higher altitudes have been developed. Flowers of Cauliflower, Broccoli, Artichoke and many ornamentals served as a food. Flowers postharvest handling is very difficult because:

they have little reserve food; contain diverse, young and meristematic parts that affect their postharvest life; and are meant to live for a short period (source of water and reserves for flowers are stems and leaves attached with flowers).

1. **Fruits**

Fruit is mature ovary with a number of associated parts. It can be categorized in to:

* Fleshy fruits: example Banana, Papaya
* Dry fruits: they release their seeds after their external cover is removed. E.g. nuts
* Vegetable fruits: they are treated as vegetables

The postharvest behaviour is also different in each category.

**Fleshy fruits:** can be classified as

Activity 2.2. Differentiate between Climacteric fruits and Non-climacteric fruits

1. **Climacteric fruits**: - have the potential to ripen after harvest. Example: Banana, Tomato
2. **Non-climacteric fruits**: - must be harvested when they are completely ripe. Example: Citrus, Avocado. They are very difficult to preserve after they are harvested since they are harvested when they fully ripen.

**V. Below ground structures**

These are underground parts of plants, adapted for the storage of food materials. They are the means by which the crop survives unfavorable seasonal conditions, and they provide the food reserve enabling the plant to make rapid growth when conditions are favorable. They serve as organs of storage and propagation. Their continued existence depends on the reserve material and utilization of starch is take place to provide energy for the produce existence.

Dormancy is present in some of these products (potato, yam) and desirable in postharvest aspect because when the produce is dormant it has low metabolic activity.

Buds are present on these structures and they determine how long the product is preserved; because buds are capable to grow and deteriorate the reserve food.

Roots are also act as storage organs for several crops like Carrot, Beet, Radish, Cassava and Sweet potato. Rhizomes and tubers are underground structures/specialized stems for some crops like Potato, Yam, Taro, Enset and Ginger.

Bulbs are underground stems, which serve as storage and propagation organs. There is no anatomical distinction/abscission zone/ between the stem and the leaf base and on maturation the leaf dies and shrinks, so harvesting is removal of the dead leaves and collection of the bulbs but the leaves continue further development.

When we see the tomato, it has abscission zone between the fruit and the fruit stalk which protects further growing, but in bulbs there is no such anatomical structure and the bulb is exposed to wounding and continuous development. To summarize, the structure and response, horticultural product structures generally are perishable, but there is a great difference among different structures.

## 2.2. Composition of fruits and vegetables

### Activity 2.3. Name the main composition of fruits and vegetables

### 2.2.1. Water

The moisture content in horticultural crops is the most abundant constituent and ranges from 65% - 95%. It is an important component of product quality that is related to turgidity, freshness, firmness, and succulence of the harvested product. It is also part of the weight of the produce and quantitative loss will happen when the water content of the produce reduced.

Most vegetables and fruits = 80 g water/100 g produce

Cucumber, lettuce, melons = 95 g water

Starch tubers, seeds, yam, cassava, corn = less water but > 50 g

The water content of the produce depends on

* + - Available water at harvest
		- Diurnal variation in Temperature and RH

Therefore, for most harvesting should be at maximum possible water content because it results in crisp texture, esp. in leafy vegetables.

### 2.2.2. Carbohydrates

Carbohydrates are the most abundant biochemical constituents in plants, representing (50 - 80%) of the dry weight of the plant. They are also the largest constituents (2% - 40%) of harvested fruits and vegetables and functions as a form of stored energy reserves and make up much of the structural frame work of the cells.

### The main types of sugars in fruits & vegetables are:

### Sucrose, glucose, and fructose

### Glucose and fructose occur in all produce and are often present at similar levels

### Sucrose is only present in about 2/3 of produce

### Highest level of sugars are found in tropical and subtropical fruits, with grape being the only temperate fruit listed

|  |  |  |  |
| --- | --- | --- | --- |
| Produces | Glucose | Fructose | Sucrose |
| Apple | 3 | 6 | 2 |
| Banana | 4 | 4 | 10 |
| Beet root | <1 | <1 | 8 |
| Capsicum | 2 | 2 | 0 |
| Grape | 8 | 8 | 0 |
| Onion | 2 | 2 | 1 |
| Orange | 2 | 2 | 4 |
| Peach | 1 | 1 | 5 |
| Pear | 2 | 7 | 1 |
| Pine apple | 1 | 2 | 5 |
| Tomato | 1 | 1 | 0 |

 Sugar content (g/100g fwt) of some fruits & vegetables

### Beet root contains the highest sugar among vegetables (8 g/100 g) with sucrose being the only sugar present. Much of the sensory appeal for fruits is due to sugar since sweetness is the universal innate human taste preference. Produces such as cassava and yam commonly contain > 20g / 100 g as starch.

### Starch from - Plantain, cassava, yam, taro, Sweet potato and potato provide the bulk of energy in the diet of subsistence group

### Cellulose, pectin substances and hemicelluloses are the main carbohydrate polymers that constitute fiber. Dietary fiber is not digested by humans because enzymes are not secreted that can break down polymers to monomers that can be absorbed.

### Starch – requires amylase

### Cellulose- requires cellulase

### Pectin- pectinase

### Dietary fiber, though has no nutritional value

### Avoids constipation

### Avoids a raft of diseases, mostly affiliated to western countries (Diseases of affluence)

### 2.2.3. Protein

The protein content in horticultural products varies between 1–2%, about 5% in legumes and contains molecules/enzymes involved in the metabolic regulations.

Fresh fruits and vegetables contain = 1g/100 g in fruits. 2 g /100 g in vegetables

Most abundant being in

* + Brassica vegetables = 3.5 g protein/100 g
	+ Legumes = 5 g /100 g

The protein is mostly functional as in the form of enzymes rather than storage organ. Fresh fruits and vegetables are not important sources of protein

### 2.2.4. Lipids

Lipids comprise less than 1 g/ 100g. Usually found associated with cuticle. Avocado and olive exceptionally have 20 g & 15 g lipid/100 g as oil droplets in the cells. Generally low lipid content is seen as a positive factor in combating the rise of heart diseases. Therefore, increased consumption of fruits & vegetables is extensively promoted by health authorities. Even high lipid fruits like Avocado and Olive have mono-unsaturated fats, which have been shown not to increase the incidence of heart diseases.

Fatty acids are substantial physical and chemical properties of lipids due to the long chain present in fatty acids. The most common fatty acids in plants range from carbon in size, with oleic and lemoleic being the most prevalent types. Among the lipids, waxes, cutin and subrin are the protective compounds of the outer surface of plants. In which waxes and cutin acts as the protective coating on much of above ground parts of the plants. Likewise, subrin; a lipid derived polymeric material is found on underground plant part and on healed surface of wounds.

These plant waxes, are extremely important during the postharvest storage and marketing of plant products in that, they function by limiting the water loss from the tissue and impeding the invasion of pathogens. Fatty acids are synthesized within the cytocol of the cell and in many cases within certain plastids (e.g. chloroplast, chromoplast).There are two path ways for these processes, one from **saturated fatty acids** and the other forming **unsaturated fatty** acids.

### 2.2.5. Vitamins

Vitamins represent a group of organic compounds that are required in the diet in relatively small amounts for normal metabolism and growth. Plant products provide a major source for many of the vitamins required by the humans. Exception would be B12, which appears to be synthesized only by microorganisms, and vitamin D, obtained from the exposure of skin to the ultraviolet irradiation. In plants, many of the vitamins perform the same biochemical functions as they do in animal cells. Consequently, most have a vital role in plant metabolism, in addition to being a source of vitamins for animals.

Typically, vitamins are separated in to two classes based on their solubility: the **water-soluble** vitamins including (thiamine, riboflavin, nicotinic acid, panthothenic acid, pyridoxine, biotin, folic acid, and ascorbic acid), and the **lipid-soluble vitamins** are, (vitamin A, E, and K). Normally the lipid-soluble vitamins are stored in the body in moderate amount; as a consequence, a consistent daily intake is not essential. The water soluble vitamins, however tend not to be stored and a fairly constant day-to-day supply is required.

### 2.2.6. Minerals

All vegetables and fruits contain important minerals, such as potassium, calcium, magnesium, phosphorus, iron, and zinc. Minerals are basic components **in secondary metabolic pathways** that produce valuable phytochemicals for normal human health. The contents of minerals in vegetables are variable; green vegetables have higher amounts of calcium and iron than root vegetables. Calcium is not only associated with preventing osteoporosis, but it also appears to have protective effects in some types of cancer, most recently colon cancer.

### 2.2.7. Organic acids

Organic acids are major components of fruits and some vegetables. The acidity of fruits arises from the organic acids that are stored in the vacuole, and their composition can vary depending on the type of fruit. In general, young fruits contain more acids that may decline during maturation and ripening due to their conversion to sugars (gluconeogenesis).Organic acids are present in a significant concentration in a number of harvested plants, and the level of organic acids present often represents important quality parameters in many fruits. Many organic acids have multiple functions in the plants. In addition, in food produce, organic acids share a significant portion of the characteristic flavour, both taste and odour. Organic acids also have very important role in the TCA cycle. The number of organic acids present in postharvest products include: glycolic acid, lactic acid, glyceric acid, pyruvic acid, glycoxylic acid, oxalic acid, succinic acid, fumaric acid, malic acid, etc. Organic acids play important role in harvested products. Where they are found in high concentration, they represent a readily available source of stored energy that can be utilized after the product is severed. In food products organic acids may take a significant portion of the characteristic flavour; taste and odour. Aromatic compounds like esters of organic acids represent characters that impart the major portion of the characteristic aroma.

The dominant acids are:

* + Citric acid (Citrus)
	+ Malic acid (Banana)

Others are:

* + Tartaric acid (grapes)
	+ Oxalic acid (Spinach)
	+ Isocitric acid (black berries)

Organic acids contribute to the taste, particularly of fruits

The balance between sugar and acids gives rise to the desirable taste of specific produce.

* High sugar and High acid - Good taste
* Low sugar and High acid - Tart test
* High sugar and Low acid- Bland test
* Low Sugar and Low Acid- Tasteless

###

### 2.2.8. Plant pigments

Human lives are surrounded and in many ways dominated by plant colors which are due to the presence of pigments within the plants and their interaction with sun light striking them, which some of them will be absorbed by photosynthesis. These plant pigments are separated in to four primary classes based on their chemistry known as; Chlorophyll, Carotenoids, Flavonoids and Betains.

1. **Chlorophyll : The plant body attains the green color, which is the result of the presence of the chlorophyll pigments. Chlorophylls are the primary light accepting pigments that help plants to carryout photosynthesis through the fixation of carbon dioxide and the release of oxygen. There are four types of chlorophylls named as, a, b, c and d, in which c and d are present in limited number of plant species. Chlorophylls are hydrophobic (water insoluble) and their function is to absorb light energy and convert it to chemical energy in the chloroplast.**
2. **Caroteniods:** Are a large group of pigments associated with chlorophyll in the chloroplasts and are found also in the chromoplasts. Their colors range from red, orange and yellow to brown and are responsible for much of outer leaf pigmentation. It is grouped into the carotenes and their oxygenated derivatives, the xanthophylls. In photosynthetic tissues, carotenoids functions both in the photosynthesis process and as Protestants, preventing chlorophyll molecules from being oxidized in the presence of light and oxygen. In flower and fruits, carotenoids appear to act as attractants that aid securing pollination or dispersal.
3. **Flavonoids:** Even though green is the dominant color in plants, other colors having tremendous attraction both for man and animals. Many of the intense colors of flowers fruits and some vegetables are the result of flavonoid pigments. They represent a large class of water soluble compounds with adverse range of colors (yellow, red, oranges) and are found in the cytosol and in vacuoles.
4. **Betains:** It represents a restricted group of plant pigments. Found in the flowers, fruits, and other plant parts. Give colours of yellow, orange, red and violate. Example is the red-violate pigment of beet root. Characterized from the others by being water soluble nitrogenous pigment found in the cytosol and vacuole. Its function is unknown but they may function like the anthocynonins enhancement insect or bird pollination and seed dispersal.

**Review questions**

1. “A fruit per day keeps a doctor away.” What do you understand from this sentence?
2. Leafy vegetables are highly and easily perishables. True /False. Why?
3. Knowing the composition of fruit and vegetables is essential to understand their postharvest physiology. How?

**CHAPTER THREE**

**3. Physiology & Biochemistry of produce in relation to post harvest**

**Chapter learning objectives**

**After studying, this chapter, the student should be able to:**

* Comprehend different physiological processes of harvested materials
* Explains the relationships between respiration, shelf life and quality
* Identify the role of transpiration and quality of horticultural crops
* List factors affecting respiration and transpiration
* Recognize the role of phyto-hormones to post harvest
* Enlighten how stresses affects post-harvest physiology of horticultural crops

**Content**

* + **Introduction**
	+ **Respiration**
		1. Significance of respiration in postharvest biology
		2. Factors affecting respiration rate
		3. Control measure to minimize respiratory losses
	+ **Transpiration**
		1. Water and postharvest life
		2. Factors that affect transpiration
		3. Methods of controlling transpirational losses
	+ **Role of phyto-hormones to postharvest physiology**
	+ **Stresses affecting postharvest physiology**
	+ **Review question**
	1. **Introduction**
* Fruits, Vegetables and Ornamentals are living tissues and the goal after harvest is to maintain the living nature of the commodity as long as possible.
* Should be kept alive in order to maintain their keeping qualities
* On removal from their plant, these are cut off from their natural supplies of nutrients, water & organic matter. When harvested, the commodity is severed from its **source of carbohydrates, water and minerals** and it therefore has to **rely on its own respiratory substrates** and **moisture** for survival.
* The tissues however, remain capable of continuing a wide range of metabolic activities
* Some physiological activities are desirable while others are deleterious
* However undesirable they are, physiological activities will continue.
* Complex substances are broken down for energy, required metabolites, structural components, etc.
* Cells must synthesize new complex substances.
* Thousands of such reactions are occurring simultaneously in a single cell.

Catabolism = the *breakdown* of complex substances.

Anabolism = the *synthesis* of complex substances from simpler ones.

**Postharvest life** is determined by the **intensity of physiological activity** or rate of metabolism. An understanding of the metabolic rate of the commodity is essential for extending the shelf life and maintaining consumer acceptance of harvested produce.

* 1. **Respiration**

Activity 3.1. What is respiration? Why do plants respire?

Respiration (i.e. biological oxidation) is the oxidative breakdown of complex substrate molecules normally present in plant cells such as starch, sugars, and organic acids to simpler molecules such as CO2 and H2O. Concomitant (associated) with this catabolic reaction is the production of energy and intermediate molecules that are required to sustain the myriad (countless) of anabolic reactions essential for the maintenance of cellular organization and membrane integrity of living cells.

Maintaining an adequate supply of adenosine triphosphate (ATP) is the primary purpose of respiration. The overall process of aerobic respiration involves the regeneration of ATP from ADP (adenosine diphosphate) and Pi (inorganic phosphate) with the release of CO2 and H2O. If hexose sugar is used as the substrate, the overall equation can be written as follows:

C6H12O6 +6 O2 +38 ADP +38 Pi 6 CO2 +6 H2O +38 ATP+686 kcal

**3.2.1. Significance of respiration in postharvest biology**

Activity 3.2. Correlation between respiration, postharvest life and quality

In general, there is an **inverse relationship** between respiration rates and the postharvest life of fresh horticultural crops. The higher the respiration rate, the more perishable (shorter postharvest life) the commodity. Respiration plays a major role in the postharvest life of fresh fruits and vegetables for the reasons given below.

1. **Loss of Substrate**

Use of **various substrates** in respiration can result in **loss of food reserves** in the tissue and loss of taste **quality** (especially sweetness) and **food value** to the consumer. For certain commodities that are stored for extended periods of time, such as onions for dehydration, the loss of dry weight due to respiration can be significant. When hexose sugar is the substrate, 180 g of sugars are lost for each 264 g of CO2 produced by the commodity.

1. **Oxygen Requirements**

An adequate O2 concentration must be available to maintain aerobic respiration. This should be considered in selecting the various postharvest handling procedures, such as waxing and other surface coatings, film wrapping, and packaging. On the other hand, reduction of O2 concentration to less than 10% provides a tool for controlling respiration rate and slowing down senescence.

1. **Carbon Dioxide Production**

Accumulation of CO2 produced by the commodity in its ambient atmosphere can be beneficial or harmful, depending upon each commodity’s tolerance to elevated CO2 levels. For some vegetables, increasing the CO2 concentration around them in a controlled or modified atmosphere can be used to delay senescence and retard fungal growth.

1. **Release of Heat Energy**

The heat produced by respiration (vital heat), which is about 673 kcal for each mole of sugar (180 g) utilized, can be a major factor in establishing the refrigeration requirements during transport and storage. Vital heat must be considered in selecting proper methods for cooling, package design, method of stacking packages, and refrigerated storage facilities (i.e., refrigeration capacity, air circulation, and ventilation).

**3.2.2. Factors affecting respiration rate**

Activity 3.3. Which factors do you think can affect respiration rate?

Respiration has a direct bearing on quality. Deterioration of quality increases rapidly with respiration rate. However, respiration rate is not an absolute index of quality deterioration rate because commodities with same respiration rate have different storage life

**Internal factors influence respiration**

* **Type of organ or commodity**:

 Leaves > fruits> roots.

* **Product size:**

 bigger size< respiration rate.

* **Stages of development:**

 young leaves >respiration.

* In fruits will depend on their classification as climacteric or non-climacteric.

**External factors influence respiration**

* **Mechanical damage** and product’s sanitary condition.
* **Temperature**
* **Atmosphere composition**
	+ Oxygen
	+ CO2
	+ Ethylene
* **Physical barriers**
	+ Waxes, plastic films, etc.

Respiration rate is measured by either measuring the amount of O2 consumed or CO2 produced over a given time and it is indicative of the general rate of metabolism. The **higher the rate of respiration** of a harvested product, the **faster the deterioration** and **shorter the shelf life**. Respiration has a direct bearing on quality. Deterioration of quality increases rapidly with respiration rate.

**A. Internal Factors**

i. **Type of organ or commodity**

Fruit and vegetables vary greatly in their respiration rates. Root, tuber, and bulb vegetables have low respiration rates. Fruit-type vegetables that are picked mature, such as tomato and melons, respire at a lower rate than those picked immature, such as green beans, sweet corn and okra. In general, leafy & tender vegetables (spinach, peas, corn, broccoli) have very high rates of respiration (Leaves > fruits> roots). Fruits with well-developed skin (Apple, orange, melons, etc) have lower rate than those with soft skinned (strawberry & raspberry). The respiratory rate is generally high in the developing stage which generally decrease as the tissues matures (Stages of development: young leaves >respiration).

Table 3.1. Classification of sample horticultural commodities according to respiration rates

|  |  |
| --- | --- |
| **Class**  | **Commodity**  |
| Very low | Dried fruits, nuts  |
| Low | Apple, garlic, grapes, onions, potatoes (mature), sweet potatoes. |
| Moderate  | Cabbages, carrots, figs (fresh), lettuce, nectarines, peaches, pears, peppers, plums, potatoes (immature), tomatoes |
| High  | Artichokes, Brussels sprouts, cut flowers, green onions, snap beans |
| Extremely high  | Asparagus, broccoli, mushrooms, peas, sweet corn |

Plant parts with vegetative floral meristematic tissues, such as asparagus, broccoli and green onions, have very high respiration rates. In general, the degree of perishability of fresh vegetables is directly proportional to their respiration rates. Differences among plant parts in the **surface area–to-volume** ratio and in the nature of their **surface coatings** (e.g., cuticle thickness, stomata, lenticels) influence their gas diffusion characteristics and consequently their respiration rates. Such differences are also responsible for genotypic variation in respiratory activity within a given commodity, as shown for lettuce. Pre-harvest factors, such as climatic conditions and cultural practices, can also affect the morphological and compositional characteristics of a given genotype, which, in turn, influences its respiration rate.

**There are two types of fruits**

* + **Climacteric fruits**: Manifest appearance of CO2 or ethylene peak coinciding with ripening or senesce (on or off the tree)
	+ **Non-Climacteric fruits**: are fruits that don’t show respiratory or ethylene peak

### Figure 3.1. Respiration pattern of fruit ripening

Table 3.2. Climacteric fruits and vegetable versus Non-climacteric fruits

|  |  |
| --- | --- |
| **Climacteric fruits**  | **Non-climacteric fruits**  |
| Apple, apricot, banana, fig, guava, mango, Avocado, nectarine, papaya, peach, pear, plum Plantain | Blackberry, cherry, date, grape, lemon, sweet orange, olive, lime, pineapple, strawberry |
| **Climacteric vegetables**  | **Non-climacteric vegetables**  |
| Muskmelon, tomato | Cucumber, egg plant, okra, pea, pepper, chili, summer squash, watermelon, gourd |

###  External factors

### Temperature

Temperature is the **most important environmental factor** in the postharvest life of fresh vegetables, fruits and ornamentals because of its dramatic effect on rates of biological reactions, including respiration. Respiration involves many enzymes whose activity is influenced by temperature. Limiting one enzyme affects the rest. The rise in temperature of the harvested produce increases the rate of respiration that leads the product to have undesirable characters. This is because, for every increase in temperature by 100C, the respiration rate will be double fold (Van’t Hoff rule). Respiration rate begins to increase from just above freezing and ceases at thermal death point. The rate increase is fairly linear until it approaches thermal death point where it becomes sigmoidal. Within certain temperature limits, respiration rate approximately doubles for every 10°C rise in temperature. This is called the Q10 value. It is also an indicator of the temperature sensitivity of respiration rate based on **Vant Hoff’s Law**

Q10 = Rate of respiration at (T° + 10)

 Rate of respiration at T°

Figure 4.2.The relationship between quality of fresh produce and temperature

However, for biological processes the relationship varies. Q10 values are usually high between 0-100C and fall to between 2-3 over 100C. Above 200C there often can be abnormal physiological phenomena which cause it to go very high or very low.

* + 1. **Availability of oxygen**

### The level of oxygen in the harvested perishable products determines the desirable or undesirable nature of that particular plant product. Respiration can take place with or without O2. But anaerobic respiration is undesirable because of off-flavor production. Oxygen levels higher than air (21%) don’t necessarily increase respiration rate while levels below 20% decrease the respiration rate. Air contains about 20 % of the oxygen essential to normal plant respiration, during which starch and sugars are converted to carbon dioxide and water vapor. When the air supply is restricted and the amount of available oxygen in the environment falls to about 2 % or less, fermentation instead of respiration occurs. Fermentation breaks down sugars to alcohol and carbon dioxide, and the alcohol produced causes unpleasant flavors in produce and promotes premature ageing Therefore, the extinction point of oxygen level when kept at minimum concentration is important to maintain aerobic respiration in a storage chamber of the produce. However the lower limits of O2 tolerance must be known to enable slowing down of respiration while avoiding anaerobic metabolism.

The minimum oxygen level necessary to maintain aerobic respiration in a storage chamber is called Extinction point (EP).Storage chambers should have proper ventilation to maintain O2 level above the EP. Waxing alters the skin porosity and rate of diffusion of CO2 and O2. The respiratory quotient (RQ) balance is maintained until O2 reaching the EP level, but once below the EP, it results in a significant increase in the RQ.

Figure 3.3.A schematic representation of the effects of O2 concentration on aerobic and anaerobic respiration rates of fresh vegetables.

### Presence of carbon dioxide

Carbon dioxide, which is the product of respiration, the presence of excess CO2 favors suppression of respiration. Generally, CO2 concentration up to 5% has beneficial effects in reducing respiration. While at higher concentrations it also has fungicidal effect. However, the product must be tolerant to high CO2 level. E.g. Strawberry

Figure 3.4. Relationship between CO2& respiration

Usually high RQ values with normal substrates may indicate onset of anaerobic respiration, while usually low RQ values may suggest incomplete oxidation to CO2. The composition of a commodity frequently determines which substrates are utilized in respiration and consequently the respiratory quotient (RQ). The RQ is defined as the ratio of CO2 produced to O2 consumed (measured in moles or volumes). Depending on the substrate being oxidized, RQ values for fresh vegetables range from **0.7 to 1.3** for aerobic respiration. When carbohydrates are being aerobically respired, the RQ is near 1, while it is <1 for lipids and >1 for organic acids. Very **high RQ** values usually indicate **anaerobic respiration** in those tissues that produce ethanol. In such tissues, a rapid change in the RQ can be used as indication of the shift from aerobic to anaerobic respiration.

RQ = CO2 produced / O2 consumed

* + 1. Ethylene production

Ethylene is commercially used as ripening agent. It is produced in trace amounts as a result of respiration. Ethylene in the case of climacteric does not change the peak of respiration, instead it brings a shift in time of peak development, whereas for non- climacterics which have no respiratory peaks but a uniform respiration rate, the application of ethylene helps for the formation of respiratory peaks or Rate of respiration is dramatically increased. Ethylene stimulates a rise in respiration in both climacteric and non-climacteric fruits. In climacteric fruits, it shorten the time to the respiratory peak i.e. hastens ripening.

### Stress

Injury (Chilling injury, freezing injury, physical and mechanical damage) –results in hastening respiration rates. Physical stress stimulates the respiration rate of fresh vegetables and fruits. For example, impact bruising of mature-green tomatoes increases their rates of respiration and ethylene production during subsequent ripening at 20°C. The extent of this increase in respiration rate is usually proportional to the severity of bruising; however, extensive injury can actually depress respiration. Any mechanical injury such as cutting, abrading, slicing, and shredding of vegetables during harvesting, handling, or processing into fresh-cut or minimally processed, value-added products increases their respiration rates. The magnitudes of CO2 production and O2 consumption increase with the degree of wounding. For example, the respiration rate of grated or shredded carrots is higher than that of sliced carrots, whose respiration rate is higher than that of whole-peeled carrot sections. During physical damage isolated enzyme & substrates contact is created. This contact triggers various biochemical reactions (Browning and softening of tissue)

### Growth regulators

Several PGR used pre and post-harvest application has influence on product quality and respiration rates

* 1. Delayed or accelerated ripening (Alar)
	2. Higher yield & greater diseases resistance - GA
	3. Improved color-Alar
	4. Prevention of abscission-NAA
	5. Sprout inhibitor (MH)
		1. **Control measures to minimize respiratory losses**

Activity 3.4. How do you think we can minimize respiratory losses to prolong shelf life and maintain quality of produces?

1. **Temperature control**
* Harvest at cool times
* Cool down & transfer produce to cold store as fast as possible
* Maintain lowest permissible temperature
* Maintain the cold storage properly (good air circulation & refrigeration)
* Product protection from sun heat (full sunlight) after harvesting.
* Pre-cooling treatments to remove field heat.
* Refrigeration.
* Maintaining the cold chain.

**N.B.**A key factor affecting product deterioration rate. Temperature is the most effective tool for extending the shelf life of fresh horticultural commodities. Has a significant effect on spores germination and pathogenic growth.

1. **Maturity**
* Harvest vegetables at appropriate stage for intended use
* Harvest fruits at mature but at sufficiently pre-climacteric stage
1. **Reduce availability of oxygen**
* Use controlled atmosphere storage
1. **Add CO2 to the environment**
* Use CA (controlled atmospheric) storage
* Use excess CO2 where permissible
1. **Ethylene (C2H4)**
* Avoid Ethylene producing chemicals on produce intended for long storage
* Scrub ethylene from storage rooms
1. **Others (stress, injuries)**
* Handle the produce carefully!!
	1. **Transpiration**

Activity 3.5. Define transpiration.

Generally, fruits, vegetables and ornamentals contain 65 to 95% moisture. After harvest they continue to lose this moisture through natural pores or directly through thin skin. This **loss of moisture** is called **transpiration**. But they cannot replace this moisture due to detachment from plant roots. The rate of losing moisture depends upon the moisture contents in their surrounding environment. Lesser the moisture in their surroundings, greater will be the force to pull moisture out of the produce. Transpiration is **also a destructive process** by which the produce loses its **freshness** and eventually leads to deterioration. Transpiration is the second most important factor with respect to quality loss during storage and transportation. It also contributes to cooling of the produce.

**Significance of transpiration during plant growth**

* + Cooling effect,
	+ Mineral salt and water absorption &
	+ Mineral salt distribution

**Transpiration represents economic loss**

* + 3-4% moisture loss can make the produce unsalable
	+ Actual moisture loss that commodities can withstand varies from: 3% for leafy vegetables, 5% for common vegetables to about 10 % of onions.
	+ In addition, transpiration can result serious quality loss ( Appearance, Texture and Flavor)
* Wilting, shriveling, shrinkage, drying, dehydration, desiccation, etc are results of transpiratory activity.

Transpiration occurs through specialized tissues. Gas & water from fruits and vegetables exchange occurs through specialized surface structures like **Stomata**, **guard cells, lenticels**, wax, cuticle, cuticular membrane, corky tissue, suberin, etc. Leaves may contain as many as 50,000 stomates per cm2 while orange peel may contain about 1500 stomates per cm2.

* + 1. **Factors that affect transpiration**
1. **Environmental Factors**

Environmental factors—such as humidity, temperature, pressure, and air movement determine the magnitude of the transpirational driving force

1. **Humidity**

Air spaces are present inside all plants so that water and gases can pass in and out of all their parts. The air in these spaces contains water vapor, a combination of water from the transpiration stream and that produced by respiration. Water vapour inside the plant develops pressure causing it to pass out through the pores of the plant surface. The rate at which water is lost from the parts of plant depends on the difference between the pressure of water vapour inside the plant and the pressure of water vapour in the air. To keep water loss from fresh produce as low as possible, it must be kept in a moist atmosphere.

1. **Temperature**

Evaporation involves the escape of water molecules from the surface and depends on their free energy. Assuming other factors are held equal, raising the product temperature increases the free energy of the water molecules and, accordingly, their potential for evaporation.

1. **Air movement**

Air movement assists in better heat transfer to effectively transfer the heat of respiration and any sensible or field heat associated with the produce. On the other hand, promotes the mass transfer in terms of removing moisture transpired by the produce from its neighbor. This results in further transpiration. If moisture that comes out the produce is held in the immediate neighborhood, this would help to reduce the ***wvpd*** and hence its transpiration rate as would happen, in packaged produce

The faster the surrounding air moves over fresh produce, the quicker water is lost. Air movement through produce is essential to remove the heat of respiration, but the rate of movement must be kept as low as possible. Well-designed packaging materials and suitable stacking patterns for crates and boxes can contribute to controlled air flow through produce.

1. **Respiration**

Respiration produces heat and moisture. The heat if not removed efficiently, can rise the produce temperature and hence its transpiration.

1. **Physical/Mechanical damage**

Wounds, cuts etc caused mechanical or physical damages increase the transpiration rate because. they expose the cellular components directly to the environment without the normal protection that was previously offered by the protective tissue.

1. **Maturation and Ripening**

Wardlaw and Leonard (1936, 1939, and 1940) carried out the earliest research on the relationship of ripening and transpiration in bananas and other tropical fruits. Ripening ‘‘Gros Michel’’ bananas kept at 29°C and 85% RH transpired at a constant rate during the pre-climacteric period, but this rate rose at the beginning of the climacteric period. After the climacteric, a steady state was attained, but at a rate twice as high as before the climacteric. Mangoes and papayas also underwent a similar sequence of changes in transpiration rates. In contrast, the rate of water loss from apples (Smock and Neubert, 1950) and from several avocado cultivars did not change with ripening (Aharoni*et al*., 1968). Furthermore, plums were found to lose more water when unripe than when ripe (Sastry*et al*., 1978). However, Wolstenholme (1992) showed that the rate of water loss in cold-stored avocado depends on its maturity at harvest and is lower in very mature, tree-stored fruit than in less mature, early-harvested fruit.

1. **The influence of the type of produce and surface area on water loss**

The rate at which water is lost varies with the type of produce. Leafy green vegetables, especially spinach, lose water quickly because they have a thin waxy skin with many pores. Others, such as potatoes, which have a thick corky skin with few pores, have a much lower rate of water loss. The significant factor in water loss is the ratio of the surface area of the type of parts of plant to its volume. The greater the surface area in relation to the volume, the more rapid will be the loss of water.

* + 1. **Methods of controlling transpirational losses**

Activity 3.7. How do you think we can control transpirational losses?

1. **Maintain as high RH in the chamber as possible.**
	* For this, several techniques (humidification, jacketed storage) are employed
2. **Maintain a low temperature difference between the produce and the cooling coils**
	* This will reduce the chances of the cold air being cooled below its dew point.
	* This is achieved by maintaining large cooling surfaces, better refrigeration capacity, moderate high air speeds, proper stacking of produce, and prompt pre-cooling of produce prior to storage

**3. Protect from mechanical and physical injuries**

**4. Regulate moisture loss by controlling the permeability of the produce tissue.**

* + Primarily this is achieved by waxing (apples, citrus, cucumber, bell pepper, banana, etc)
	+ A good wax should have low toxicity, rapid drying characteristics, strong adherence characteristics, high gloss and low cost.

**5. Prepackage in polymeric films**

* + This is very effective way of controlling moisture loss by **maintaining high RH** levels within the package.
	+ **Perforations** must be provided to allow gas escape otherwise CO2 gases will build-up inside.
	+ **Permeability** of film to oxygen is important to keep the required **minimum oxygen** levels inside the package.
	+ The produce is allowed to transpire to accumulate the moisture to the maximum level which will automatically suppress the subsequently transpiration.
	1. **Role of Phyto-hormones to Post harvest**

Activity 3.8. Discuss the roles of plant growth regulators for postharvest physiology.

Most evidence indicates that generally more than one hormone is involved in those physiological responses attributed to hormonal influence, and the effects observed are due more to the hormonal balance than to the activity of any one hormone. Even less is known about the role of hormones in the postharvest physiology of cultivated horticultural crops, most of which are removed suddenly from the natural environment and sometimes mutilated in the harvest process. Fresh horticultural products are living tissues that are subject to continual change after harvest.

* + 1. **Ethylene**

Ethylene effects are wide and include fruit ripening, flower and leaf senescence, and also leaf abscission, so that ethylene has an obvious result on leafy vegetables. Storage of fruits and vegetables can therefore be prolonged by ethylene removal. This can be done by using ethylene scrubbers—e.g., alkaline potassium permanganate on a silica carrier—flushing with nitrogen gas, or by hypobaric storage.

Wounding during harvest and transport affects storage, since transient ethylene production is also triggered by stress or injury, and many of the bacterial pathogens have the capacity to synthesize ethylene. In many fruits, ripening is accompanied by an increase in respiration termed the *climacteric*, and there is a pronounced increase in the production of ethylene just before the increase in respiration in climacteric fruit. Ethylene plays a significant role in the rather dramatic integrated sequence of physiological and biochemical changes that occur with the climacteric and ripening, and promotes the loss of chlorophyll. These changes include softening, color change, & the accumulation of sugars (or lipids, as in avocado) &aromatics, along with a decline in organic acids, catalyzed by specific enzymes. Ethylene is commonly referred to as the ripening hormone and has a cascade effect in climacteric fruit, leading to the ‘‘one rotten apple in the barrel’’ expression.

**Some negative effect of ethylene**

* Quality loss is accentuated by ethylene, which can induce de-greening and leaf abscission to the point of making produce unmarketable. The storage life of broccoli and Brussels sprouts can be shortened by ethylene applications.
* A specific effect of ethylene in stored carrots is the development of bitter flavor due to ethylene-induced isocoumarin formation. This isocoumarin synthesis and the increased respiration induced by ethylene in carrots were influenced by their physiological state, wounding, and the O2 level.
* Ethylene is known to promote loss of chlorophyll & was used to promote the blanching of celery
	+ 1. **Auxins**

Auxins are involved in many plant responses, including cell enlargement and elongation, cell differentiation, and control of apical dominance. The main auxin in most plants is **indole-3-acetic acid (IAA).** Indole acetic acid influences ethylene formation through the induction of ACS; therefore its effects are of interest during fruit ripening. The pattern of IAA levels found in stone fruits supports this notion of IAA levels inducing ethylene production during fruit ripening.

* + 1. **Gibberellins**

Among other effects, gibberellins (GAs) affect cell elongation and bolting in plants. Endogenous levels of gibberellins are thought to be high in very young fruit, and they may play a role in retarding senescence. The respiration response typical of a climacteric fruit is retarded by GA3 treatment in tomato fruit, which delays the ripening pattern. Fruit softening is delayed by GA. Similarly, color development in tomato is retarded and modified by GA. Fruit ripening is associated with the conversion of chlorophyll-containing chloroplasts to carotenoid-containing chromoplasts, and GA3 delays appearance of plastid-localized lycopene during ripening of tomatoes but does not suppress chlorophyll degradation. Applied Gas do enhance re-greening color changes in some fruit, but despite the effect of applied.

* + 1. **Cytokinins**

Cytokinins delay senescence and maintain green color and fresh appearance in many leafy vegetables. High levels of endogenous cytokinin can also delay fruit ripening, and levels may decline as ripening proceeds. Senescence in leaves can be delayed by cytokinin and, in one aspect; fruit ripening can be regarded as a senescence phenomenon. Applied cytokinins are often effective in prolonging the shelf life of leafy vegetables by slowing down senescence. Application of the synthetic cytokinin 6-benzylaminopurine (BA) as a postharvest dip delays senescence and maintains green color and fresh appearance in crucifers as well as many other leafy vegetables, including escarole and endive, spinach, green onions, celery, and asparagus. Exogenous cytokinin applications also extended the storability of broccoli. Good quality in broccoli was maintained by BA treatment and low temperatures of 2°C.

* + 1. **Abscisic acid**

Many postharvest phytohormone studies have been concerned with the induction and termination of the rest period, and whether rest is induced and prolonged by an endogenous inhibitor. The nature of the inhibitor has been under study since the presence of a growth inhibitor in a potato peel extract fraction. It is also not the only controlling factor in true dormancy or rest. ABA is an important hormone, mediating seed development, stomatal closure, and plant stress responses.

Developing sinks serve as sites for accumulation of ABA produced in source leaves, as seen in developing soybean seeds. In a number of fruits, which are developing sinks, the level of free ABA is constant during maturation and increases during ripening, and the rise in ABA is seen in both climacteric and non-climacteric fruits. Free ABA accumulates in both attached and detached tomato fruit unless the fruit is detached very early, showing that ABA is also synthesized in the detached fruit and is not dependent only on translocation from the mother plant. Also the ratio of free bound ABA is about 10:1 throughout ripening in avocado, so that the increase in free ABA in fruit must represent net synthesis rather than release of the bound form.

### Jasmonates

Jasmonic acid (JA) and methyl jasmonates (MJ) collectively referred to as jasmonates, are naturally occurring plant growth regulators that are widely distributed in the plant kingdom, and are known to regulate various aspects of plant development and responses to environmental stresses. Jasmonates play an important role as signal molecules in plant defence responses against pathogen attack. Jasmonates have been shown to activate genes encoding antifungal proteins such as thionin, osmotin, a novel ribosome inactive protein RIP, and several other genes involved in phytoalexin biosynthesis. Recently, it was reported that methyl jasmonates can be applied effectively, as a postharvest treatment, to suppress grey mold rot caused by B. cinerea in strawberry. When applied at low concentrations, jasmonates are potential postharvest treatments to enhance natural resistance and to reduce decay in fruit. Since they are naturally occurring compounds and are given in low doses, jasmonates provide a more environment-friendly means of reducing the current chemical usage.

* 1. **Stresses affecting Post-harvest physiology**

Activity 3.9. What is stress? Discuss in group the causes of stress.

Stress is a significant deviation from the conditions optimal for life, eliciting changes and responses at all functional levels of the organism, which may become permanent. The term **stress** is also used for an external factor capable of inducing a potentially injurious strain in living organisms. As a stress is imposed, plants usually exhibit a cascade of responses, occurring on different time scales, that involve molecular, biochemical, physiological, and morphological adjustments leading to stress tolerance or avoidance.

* + 1. **Ethylene due to stress**

Plant tissues produce ethylene when they are under unfavorable conditions or environmental factors. Stress ethylene can be caused by a biotic (mechanical, wounding, chilling, drought, flooding, and chemicals) and biotic stimuli (insect attack, and viral, bacterial, and fungal diseases). Ethylene increases respiration, induces certain genes, and modifies certain metabolic activities.

* + 1. **Mechanical stress**

Fruits and vegetables are subjected to wounding and mechanical stress during harvesting, sorting, packing, and transportation, which may adversely affect ripening and senescence processes. Wounding refers to stress caused by cutting, gashing, abrasion, stabbing, bruising or intruding, which may cause injury on the surface or to the inner tissues. Mechanical stress is encountered when growth of plant tissues and organs is restricted by certain physical barriers (mechanical impedance). Wounding has relevance to the development of crop resistance to plant pathogens that require a wound lesion for infection. Wounded plant tissues and organs release ethylene. Wounding causes many changes at the tissue, cellular, sub-cellular, and biochemical levels that can reduce shelf life and negatively affect the fresh market and processing quality of vegetables. The best way to increase quality is to reduce the potential for impacts that cause wounding. To accomplish this goal, we can reduce the number of handling steps from field to customer, reduce the number of transfers to and from containers, reduce the height of falls during transfers or pad the receiving containers, pad transport containers or secure the produce in containers to reduce vibration, and reduce the number of sharp edges, perhaps by padding, to which the produce is exposed. Once mechanical stress has been minimized in a particular setting, other factors become important. Removal of field heat and proper storage parameters, such as reduced storage time, low-temperature storage, and controlled or modified atmospheres can be beneficial. However, the best means to minimize losses due to mechanical injury is through motivated employees who are careful and conscientious in their handling of the produce.

* + 1. **Physiological aspects of postharvest water stress**

Water deficit directly or indirectly affects practically all the physiological processes in plant tissues. Of all the physiological processes in leaf tissues, cell growth appears to be the most sensitive to water stress. Rate of cell elongation is affected by even a small reduction of tissue water potential. High sensitivity to water stress has also been reported for protein and cell-wall syntheses and for nitrate reductase. Moderate water stress causes changes in abscisic acid and cytokinin concentrations in leaf tissues, stomatal closure. The respiration pattern in harvested avocado fruit was shown to be markedly altered by water stress. The process of sugar accumulation is relatively resistant to water deficit and are disturbed only by more severe stress,

Water stress affects tissues in the same way as senescence. The physiological changes occurring in harvested green and red bell pepper fruit were investigated in relation to the development of water stress. The decline in tissue water potential was accompanied by softening, decreased insoluble pectin, increased soluble pectin and increased electrolyte leakage, all processes attributed to senescence. When water stress was alleviated by keeping peppers in a water-saturated atmosphere, all of these physiological changes were prevented or markedly slowed. Water stress hastens and possibly triggers the onset of senescence in harvested fruit. The common mechanisms of water stress and senescence may be related to deterioration of cell membranes by increased formation of free radicals.

Water stress acts to bring about changes in hormonal balance similar to those caused by senescence: a marked drop in endogenous levels of gibberellins and cytokinins and a marked rise in the level of abscisic acid and ethylene. These effects were reversed upon removal of stress by placing plant organs (orange fruit and leaves, lettuce leaves) in a water-saturated atmosphere.

**Review questions**

1. Are harvested horticultural crops are still living organs? How?
2. Is respiration desirable or detrimental for harvested product? If yes, how and if not why?
3. List and discuss the factors that affect respiration.
4. What is the relationship between respiration and temperature?
5. Can we stop respiration after harvest?
6. Compare and contrast climacteric and non-climacteric fruits?
7. Discuss the advantages and disadvantages of ethylene?
8. What factors tend to increase water loss?
9. Describe the role of phyto-hormones for postharvest physiology of horticultural crops.
10. How do we control stress and injury?

**CHAPTER FOUR**

**4. Metabolic changes during maturity, ripening and senescence**

**Learning objectives**

At the end of this section students will be able to:

* Realize different metabolic processes during maturity, ripening and senescence

**Content**

* 1. Stages of fruit and vegetable development
	2. Change in structure
	3. Change in composition

## 4.1Stages of fruit and vegetable development

Developmental period of plants begins with germination and end up on death and it can be viewed at both the whole plant as well as organ level.

Figure 4.1. Developmental stages of fruits and vegetables

**Terminologies**

**Growth: -** the time of active cell division and enlargement which leads to increase in size or volume.

**Maturity: -** the time period when the plant has completed its active growth (vegetative stages, stages of flowering and seed production) stages.

**Ripening: -** the developmental stage of fruits and vegetables which is characterized by a series of diverse physical and chemical changes and follows maturation.

**Senescence: -** refers to the time when a series of deteriorative changes occur leading to the natural death of the plant

The developmental cycle of plants is usually interrupted by harvesting. For example: asparagus and lettuce are harvested when they produce sprouted stems; fleshy fruits harvested when they are at mature/ripe stage; and seeds of grains harvested when they completed their development including senescence.

### Maturity

A critical time for growers of fruit and vegetables is the period of decision on when to harvest a crop. Normally any type of fresh produce is ready for harvest when it has developed to the ideal condition for consumption. This condition is usually referred to as harvest maturity. Confusion may arise because of the word maturity since, in the botanical sense, this refers to the time when the plant has completed its active growth (vegetative growth) and arrived at the stage of flowering and seed production (physiological maturity) as shown in Figure 4.1. Harvest maturity thus refers to the time when the "fruit" is ready to harvest and must take into account the time required to reach market and how it will be managed en route. This time lag usually means that it is harvested earlier than its ideal maturity.

Maturity can be categorized as physiological and harvest maturity. Physiological maturity refers to the stage of development when the plant is capable of shifting from vegetative to reproductive growth stages whereas, harvest maturity refers to the stage of development that is considered an ideal condition for consumption/ harvest. However, harvest maturity doesn’t mean immediate utilization or consumption.

For example, Banana for long distance transport should be harvested when 3/4th of the ripened stage (green stage) is completed and the rest of ripening stages will be completed during storage and transportation.

Harvest maturity consists of different considerations.

1. **Stages of harvest: -** horticultural crops have wide variations in their stages of harvest maturity. For example, fruits reach at their harvest maturity when they are at mature/ripe stage, whereas, vegetables harvested at all levels of developmental cycles/stages (sprouts, stems and leaves, inflorescences, root and tubers at various developmental stages, and seeds).
2. **Duration of the period of harvest maturity:** the period of harvest maturity can be stayed in several months (example; root crops like Cassava and Enset) or in weeks (example; oranges, coffee) or even in hours (example; flowers).

Optimum maturity/the right time for harvest/ determine: optimum quality, postharvest period, and maintenance of quality after harvest. Most growers identified/decide optimum harvest maturity (when to harvest) by looking and sampling. Judgments are based on: sight (colour, size and shape), touch (texture, hardness or softness), smell (odour or aroma), taste (sweetness, sourness, bitterness), or resonance (sound when tapped).

Experience is the best guide for this kind of assessment. Newcomers to fresh produce-growing may find that learning takes time. Harvest maturity can readily be observed in some crops: bulb onions when their green tops collapse and potatoes when the green tops die off. Other crops can be more difficult: for example, avocados remain unripe off the tree after maturity.

Different actors have different maturity criteria. For example, for the producer optimum maturity means when the produce fetch maximum price and he/she may harvest produce even when they do not reach at the right harvest maturity. For the transporter, the optimum maturity is the condition when produce can reach at the desired utilization site with minimum damage. For the store people, optimum maturity means the stage of the product that can take minimum place and the product can stay for maximum possible period without appreciable loss. For the consumer, optimum maturity means the stage at which the product has maximum nutritional and visual quality.

**4.1.1.1. Maturity indices**

Importance of Maturity Indices

* Sensory and Nutritional Quality
* Use Fresh market or Processed
* Adequate shelf - life
* Facilitate marketing standards
* Productivity

**PHYSIOLOGICAL MATURITY:** The stage of development when a plant part will continue development even if detached; mature fruits

* Reached at the end of development
* May not coincide with ripening maturity

**HORTICULTURAL MATURITY:** The stage of development when a plant part possesses the necessary characteristics for use by consumers

* Reached well before end of development
* May or may not be followed by physiological process

e.g. cucumber

**Maturity Indices for different crops**

**Onions/Garlic**

* + Size
	+ Drying and collapse of the “neck”
	+ Drying of leaf scales

**Potatoes**

* + Death of the plant
	+ Size of tubers
	+ Starch content; specific gravity
	+ Periderm development

**Asparagus**

* + Size
	+ Apex closed

 **Broccoli/Cauliflower**

* + Size
	+ Florets closed

**Carrot**

* + Size

 **Lettuce, head**

* + Size
	+ Firmness, solidity
	+ Flavor-sweetness, bitterness

 **Lettuce, Romaine**

* + Size
	+ Number of leaves

**Beans**

* + Size
	+ Seed development

**Summer Squash & Cucumber**

* + Size
	+ External color

**Peppers**

* + Size
	+ Color
	+ Firmness
	+ Seed development

 **Tomato**

* + External and Internal color
	+ Development of locules (jelly)
	+ Firmness
	+ Size
	+ Development of cuticle

**Mango maturity indices:**

* Fullness of shoulders
* Internal and external color
* Lenticels and hairs on pit
* Starch content; specific gravity

**Apples**

Days from full bloom

* Time/temp (heat units) from anthesis
* Days from harvest to onset of ethylene production
* Ground color
* Soluble solids content (SSC)
* Flesh firmness and SSC
* Starch disappearance pattern
* Internal ethylene concentration
* Changes in firmness or starch content

**What is a good maturity index?**

* Simple, easy to carry out
* Objective vs subjective indicators
* Related to quality
* Related to storage life
* Represents a progressive change with maturity
* Permits prediction of maturity from year to year
* Inexpensive

**Predicting Maturity**

* Days from planting to harvest
* Progressive changes in size, composition
* Difficult to do; need new tools and methods
	+ Nondestructive firmness measurement: fruits
	+ Chlorophyll fluorescence, broccoli: green tissues
	+ NIR spectroscopy: sugar concentration in melon
	+ Imaging constituents: internal defects

### Ripening

Fleshy fruits undergo a natural stage of development known as ripening. This occurs when the fruit has ceased growing and is said to be mature. Ripeness is followed by ageing (often called senescence) and breakdown of the fruit. The fruit referred to here includes those used as vegetables or salads, such as, sweet pepper, tomato, banana, avocado etc. Ripening process is marked by a series of non-reversible changes in the fruit and they transformed non-edible fruits into edible one. A number of changes are accompanied during ripening. These are: physiochemical changes, respiration and hormonal changes.

* 1. **Physiochemical changes during ripening**

Ripening involves a complex of changes which are either synthetic or degradation changes. Some of the changes that occurred during ripening are: seed maturation, softening, change in respiration rate, change in pigmentation and composition, and change in the level of hormone.

* + 1. **Softening/textural change: -**is resulted in because of hydrolysis of cellulose, hemicelluloses, and pectin substances by cellulase and pectinase enzymes which are either synthesised or activated during the process. It is one of the significant changes during ripening and it affects the edibility of the fruit and the length of time the fruit may be handled. Softening may be essential (in the development of quality) or detrimental (in fruits which are consumed in unripe state like cucumber, squash). Softening is the beginning of senescence and if it is beyond the limit, it leads to loss of quality.

**ii. Change in composition**: a series of compositional changes have been take place during ripening

1. **Conversion of starch into sugar**

The conversion of starch into sugar develops sweetness of the fruit and increase quality, because the glucose served as a precursor for the synthesis of flavour and aroma elements. In some fruits, total conversion of starch into sugar is take place. For example in Banana; the starch and sugar content of the fruit at mature green stage is about 20 – 30% and 1%, respectively, and during ripening about 1% and 14 – 15% respectively. Generally, the highest amount of sugar present in the fruits after it has been harvested is attained in different ways among climacteric and non-climacteric fruits. In climacteric fruits, sugar content increased after harvest due to hydrolysis of starch present in the fruit, whereas, non-climacteric fruits harvested when they are fully and the increased sugar content in the ripened fruit is attained through transport from the mother plant.

1. **Change in the level of organic acids**

Generally, the level of organic acids during ripening is decreased except in banana and pineapple, in which there is an increased in organic acid level during ripening. The reduction of organic acids during ripening is due to utilization of acids as a respiratory substrate and served as C-skeleton for the synthesis of new molecules. The sugar acid ratio is the most important indicator of maturity.

1. **Change in nitrogenous compounds**

Metabolic activities are high during ripening and both synthesis (the level of free amino acid is low) and degradation (conversion of protein into smaller units called amino acids, hence the level of free amino acids is high) of nitrogenous compounds take place. The synthesis reaction involves for the synthesis of enzymes.

1. **Change in pigmentation**

Colour is used as an index for the degree of ripeness (example, tomato, and banana) and as a criterion in determining ripening by consumers. Colour change occur during ripening due to two processes

* **Unmasking of already existing colours: -** during ripening, chlorophyll is degraded by the enzyme chlorophylase, as a result carotenoids (responsible for orange and red colour) and anthocynins (responsible for pink, red, purple or blue colours) become unmasked and reflect new colour of the product.
* **Synthesis of new pigments**: some fruits like Avocado and Apple retain their colour during ripening through synthesis of new pigments, while climacteric fruits are the ability to develop their colour after harvest (Tomato, Banana), but non-climacteric fruits can’t develop colour after harvest.

**Factors affecting colour changes**

* **Light:-** it accelerates the degradation of chlorophyll and also enhances the synthesis of carotenoids in tomato harvested prior to ripening
* **Temperature: -**lycopene **synthesis** in tomato is inhibited at > 30OC and citrus fruits rarely develop their orange colour in tropics when the temperature is less that about 13OC. If the temperature is < 13 OC the fruit remains green.
* **Oxygen concentration: -** with the increase in oxygen concentration carotenoid synthesis is increased.
	1. **Respiration patterns in ripening fruits**

Rate of respiration is regulated by the metabolic activity of the produce. Usually, young plants have high rate of respiration & cell division and enlargement is high and require enormous amount of carbon & energy unlike old plant that have very low respiration rate.

For developed fruits and organs there is also the same trend; initiation and fruit development require more carbon and energy and have high rate of respiration, whereas at maturity and ripening, rate of respiration decreased.

The relationship between carbon dioxide evolution and fruit ripening has been investigated widely for some of the deciduous fruits. With the apple and pear, in particular, it has been shown that changes in certain manifestations of maturity are accompanied by a greatly accelerated rate of respiration. Similar observations were made for the banana.

This rapid increase in carbon dioxide production is referred to as the "climacteric" rise in respiration. Not all fruits appear to exhibit this respiratory trend, however. In the lemon and orange, which have relatively low respiring power, no climacteric has thus far been observed. There are two characteristic types of fruit ripening that show different patterns of respiration:

**Non-climacteric fruit ripening**-refers to those fruits which ripen only while still attached to the parent plant. Their eating quality suffers if they are harvested before they are fully ripe because their sugar and acid content does not increase further. Respiration rate slows gradually during growth and after harvest. Maturation and ripening are a gradual process. Examples are: cacao, cucumber, olive, orange, pepper, mandarin, strawberry, cherry, grape, lemon, pineapple, and all vegetables except tomato.

**Climacteric fruit ripening**-refers to fruits that can be harvested when mature but before ripening has begun. These fruits may be ripened naturally or artificially. The start of ripening is accompanied by a rapid rise in respiration rate, called the respiratory climacteric (see figure 3.2, left side). After the climacteric, the respiration slows down as the fruit ripens and develops good eating quality. Examples are: apple, avocado, guava, fig, mango, passion fruit, banana, melon, papaya, tomato, peach pear, water melon.

During the ripening process, some fruits evolve large amounts of ethylene, sometimes referred to as an autocatalytic increase in ethylene production, which occurs in conjunction with an increase in respiration referred to as the respiratory climacteric. Fruits are generally classified into climacteric or non-climacteric types on the basis of the pattern of ethylene production and responsiveness to externally added ethylene.

The climacteric fruits characteristically show a marked enhancement in ethylene production and respiration, as noticeable by the evolution of carbon dioxide.

In climacteric fruits, their metabolic activity/respiration increase during ripening and this is mainly accompanied by the increase in ethylene production (figure 3.2, right side). Enzymatic activation may provide an explanation for the rapid acceleration in respiration rate during- the climacteric and the fall in carbon dioxide evolution in the post-climacteric stage may be the result of substrate shortage. By contrast, the non-climacteric fruits emit a considerably reduced level of ethylene.

After the initiation of ripening or harvest, several biochemical changes occur in fruits and vegetables. As some of these changes such as the development of color, flavor, and sweet taste are desirable for fruits, any sort of quality changes are ideally not desired in vegetables. Thus, strategies for the preservation of shelf life and quality in fruits and vegetables could be entirely different. It is important to know the biochemical differences between fruits and vegetables and several biochemical pathways that operate in these tissues to develop ideal conditions of storage for the preservation of shelf life and quality.

Climacteric pattern is practically important in postharvest of fruits and vegetables by allowing greater degree of flexibility in handling of products:

* Harvesting is done while the fruits are ripe/unripe
* Ripening can be induced and allow greater degree of synchronization
	+ - 1. **Hormonal changes in relation to ripening**
1. **Ethylene (CH2=CH2)**

Ethylene regulates many developmental processes including flowering, ripening, senescence, abscission, dormancy and stress. The earlier discoverers called ethylene “the ripening hormone”. In the case of fruits, an increase in the biosynthesis of the gaseous hormone ethylene serves as the physiological signal for the initiation of the ripening process. In general, all plant tissues produce a low, basal, level of ethylene. All living parts of plants including the cells of fruits produce ethylene throughout their growth and development. There is alteration in ethylene synthesis with the onset of ripening. Climacteric fruits exhibit a surge of ethylene synthesis near the onset of ripening, whereas non-climacteric fruits doesn’t show any change in the concentration of ethylene accompanying to ripening.

In climacteric fruits such as apple, pear, banana, tomato, and avocado, ethylene evolution can reach 30–500 ppm/(kg h) (parts per million, micro liter per liter), whereas in nonclimacteric fruits such as orange, lemon, strawberry, and pineapple, ethylene levels usually range from 0.1 to 0.5 ppm/(kg h) during ripening.

There are also differences between climacteric and non-climacteric fruits in response to ethylene application. Climacteric fruits respond to external ethylene treatment by an early induction of the respiratory climacteric and accelerated ripening in a concentration-dependent manner.

Figure 4.2. Difference of climacteric and non-climacteric commodities in ethylene production and respiration rates

Non-climacteric fruits, on the other hand, show increased respiration in response to increased levels of ethylene concentration without showing acceleration in the time required for ripening. Vegetables produce very low amounts of ethylene most of them with less than 0.1 *μ*L/(kg h), with slightly higher levels as in cassava (1.7 *μ*L/(kg h)), breadfruit (1.2 *μ*L/(kg h)), and cucumber (0.6 *μ*L/(kg h)) when measured at 20–25◦C.

Table 5.1.Difference between climacterics & non-climacterics in response to ethylene

|  |  |  |  |
| --- | --- | --- | --- |
| No  | Character  | Climacterics  | Non-climacterics  |
| 1 | Internal ethylene concentration | Highly variable | Low and constant through different developmental stages |
| 2 | Autocatalytic (ethylene induced) ethylene production  | Present  | Absent  |
| 3 | Response to exogenous application of ethylene | Stimulate respiration once | Stimulate respiration throughout the postharvest period |
| 4 | Magnitude of respiratory rise | Independent of ethylene concentration | Dependent on ethylene concentration |
| 5 | Respiratory rise mediated by ethylene | Irreversible  | Reversible and dependent on continued response |

Generally, 0.1 to 1 *μ*L/L is sufficient for respiratory rise.

There are differences in the sensitivity of fruits to ethylene application. For example Avocado and Banana need 1*μ*L/L and 10 *μ*L/L of ethylene to induce ripening. There are also variations in internal ethylene concentration which is genetically controlled. The resistance of the tissue to ethylene is also varied between different fruits. The sensitivity of the tissue to ethylene is also different for various developmental stages and is highest near the onset of ripening.

How ethylene induces ripening is not exactly known till now. However, ethylene is believed to be the signal turning in climacteric fruits. In many fruits (Banana, Avocado) the rise in ethylene concentration precedes respiratory rise, whereas in some fruits (Mango, Apple) the rise in ethylene concentration occurs simultaneously with the respiratory rise.

In commercial fruit production and marketing, artificial ripening is used to control the rate of ripening, thus enabling transport and distribution to be carefully planned. Ethylene is a gaseous hormone and if ripe and unripe fruits stored together, the ethylene produced from ripen fruits may cause unplanned ripening of unripe fruits. Climacteric fruits may be harvested in green mature stage for long distance market, but if the vehicle is either uploaded with ripen fruits or where uploaded other fruits and is not properly cleaned unwanted ripening may occur and lead to over maturity while is not on the proper destination. Smoking near the fruit orchid as well as near the store also can make fruits to become ripe uniformly.

 **2. Other hormones**

In some fruits like Avocado, harvested fruits ripened more readily than those remained on the tree. There are some hormones that control the ripening process when fruits are on the tree and ripening process is initiated when they detached from the tree. In Apples for example, when fruits harvested, the rate of ethylene synthesis increases, hence there is something that hinder ethylene synthesis while the fruit is attached to the plant. Auxin is known to be the most ethylene synthesis inhibitor hormone.

### Senescence

Senescence is an integral part of the normal development of organisms and it is not happened as a result of a disease or abnormal conditions. It can be defined as a serious of endogenously controlled deteriorative changes leading to the natural death of cells, organs, plants, etc. In postharvest point of view, it is very important stage because if we can’t maintain the product metabolic rate at minimum level it might lead to the death of the produce which leads to loss of the produce. So, delaying or minimizing the death of the product is the critical objective of postharvest handling. A great loss of quality will happen during senescence even before the product completely dead. There are changes occur during senescence. At the cellular level, the following major alterations occur during senescence.

1. **Degradation of chlorophyll** which lead to colour change
2. **Degradation of protein and decrease in protein synthesis**.

During senescence, enzymes involved in anaerobic process are withdrawn from the cell.

1. **Alterations in membrane structure/Loss of membrane integrity**

Senescence is accompanied by softening, as senescence advances beyond softening stage:

* Membrane rigidity decreases as a result of loss of water
* Membrane leakiness increases which lead to removal of materials from the cell
* Altering enzymes activity

Senescence is an active process that requires energy and carbon for the changes to take place, and highly dependent on oxygen concentration (low oxygen concentration delays senescence. It is also dependent on gene activation, and enzymes which are involved in senescence are synthesised or controlled their amounts by those gene activations. Substances that inhibit RNA or protein synthesis delay senescence. The disappearing of the cell takes place in ordering fashion or orderly dismantling of cells i.e., those proteins/cells which are less important for the survival of the cell dismantled first and which are important for survival of cells like nuclear membrane, mitochondria are dismantled at the very end.

**Causes of senescence**

1. **Genetic causes**

Living things are programmed that die at certain period. Programme death can be illustrated for e.g.

* Monocarpic plants die away after they produce flowers/fruits once (e.g. Banana, pine apple).
* Perennial plants continue to live long period
* Organs- fruit ripening is one form of programmed death.
* Petals are programmed to live for a few days
* Leaves have also a certain duration of existence i.e all leaves can’t live up to the whole plant life

The plant removes organs that finish their life cycle (example; fruits, petals) or remove organs in the case of adaptation that require more energy (assimilates). Therefore, senescence in this case is advantage of the plant because it avoids the demand of more energy, but in postharvest aspect, it is disadvantageous at it leads to loss of the produce.

1. **Loss of homeostasis: -**keeping a balance for the time.

Homeostasis is an active process that needs investment to get energy for the process to be undergone. Homeostasis lost during senescence because input (stored food) and output (energy and carbon resulted from respiration) are not balanced.

Maintenance is a result of degradation and synthesis changes and these doesn’t become equal, there is loss of homeostasis. Once fruits, leaves, etc are harvested the inputs (e.g. Light) are affected and the input – output balance disturbed which result in loss of homeostasis.

**Regulation of homeostasis**

**i. endogenous regulation**

* Application of ethylene accelerates ripening in fruits, senescence of flowers, leaf abscission. Therefore, substances which inhibit the synthesis and/or action of ethylene delay senescence.
* In ethylene-insensitive plants like daylily, abscisic acid (ABA) is thought to be the primary hormonal regulator of flower senescence, and exogenous application of ABA accelerates visual senescence symptoms and regulates transcription of senescence-related genes. ABA promotes senescence, resulted in loss of chlorophyll, increased protein degradation and reduces synthesis, and alters membrane degradation.
* Application of potassium and calcium can delay/inhibit senescence

**ii. Environmental factors**

* Stress (biotic and abiotic) can induce senescence and influence its rate
* Temperature, both high and low
* Atmospheric gas composition
* Water- both deficit and excess

**CHAPTER FIVE**

**5. Quality Evaluation of Horticultural Products**

**Chapter learning objectives**

At the end of this chapter students are expected to:

* Define quality
* Know the quality evaluation standards/grads and components of quality
* Explain post-harvest quality parameters
* List and discuss the factors that determine postharvest quality of harvested produces
* Describe post-harvest management to maintain quality

**Content**

* 1. Introduction
	2. Post-harvest Quality parameters
		1. Appearance (visual) quality factors
		2. Textural (feel) quality factors
		3. Flavor (eating) quality factors
		4. Nutritional quality factors
		5. Safety factors
	3. Factors that determine post-harvest quality of harvested products
	4. Quality standards
	5. **Introduction**

]

Quality, the **degree of excellence** or **superiority**, is a combination of attributes, properties, or characteristics that give each commodity value, in terms of its intended use. The relative importance given to a specific quality attribute varies in accordance with the commodity concerned and with the individual (producer, consumer, and handler) or market concerned with quality assessment. To producers, high yields, good appearance, ease of harvest, and the ability to withstand long-distance shipping to markets are important quality attributes. Appearance, firmness, and shelf-life are important from the point of view of wholesale and retail marketers. Consumers, on the other hand, judge the quality of fresh fruits, ornamentals, and vegetables on the basis of appearance (including ‘freshness’) at the time of initial purchase. Subsequent purchases depend upon the consumer’s satisfaction in terms of flavor (eating) quality of the edible part of produce. Following is a description of the factors that contribute to the various qualities attributes of fresh produce:

**Activity 5.1. What is quality?**

Quality is difficult to define, because it has different meaning for the

* + **Producer**-one that secures maximum price
	+ **Shipper**-hard, firm cable of being transferred from orchard to market without bruising or ripening-the harder the better!
	+ **Canner**-suitable for processing with a maximum output/recovery
	+ **Consumer**-ripe, attractive with good appearance

**Therefore, quality is simply fitness for a purpose!**

* 1. **Post-harvest Quality parameters**

Quality criteria can be either external or internal

**Important quality criteria for consumers are;**

* + Appearance
	+ Condition and absence of defects
	+ Mouth feel or texture
	+ Flavor
	+ Nutritional value
	+ Safety or anti-nutritional factor

The relative importance of each quality factor depends upon the commodity and intended use.

* + 1. **Appearance (visual) quality factors**

These may include size, shape, color, gloss, and freedom from defects and decay. Defects can originate before harvest as a result of damage by insects, diseases, birds, and hail; chemical injuries; and various blemishes (such as scars, scabs, russeting, rind staining). Post-harvest defects may be morphological, physical, physiological, or pathological.

* + 1. **Textural (feel) quality factors**

These include firmness, crispness, juiciness, mealiness, and toughness, depending on the commodity. Textural quality of horticultural crops is not only important for their eating and cooking quality but also for their shipping ability. Soft fruits cannot be shipped over long distances without substantial losses due to physical injuries. In many cases, the shipment of soft fruits necessitates that they be harvested at less than ideal maturity, from the flavor quality standpoint.

* + 1. **Flavor (eating) quality factors**

These include sweetness, sourness (acidity), astringency, bitterness, aroma, and off-flavors. Flavor quality involves perception of the tastes and aromas of many compounds.

An objective analytical determination of critical components must be coupled with subjective evaluations by a taste panel to yield useful and meaningful information about the flavor quality of fresh fruits and vegetables. This approach can be used to define a minimum level of acceptability.

In order to assess consumer preference for the flavor of a given commodity, large-scale testing by a representative sample of consumers is required.

* + 1. **Nutritional quality factors**

Fresh fruits and vegetables play a significant role in human nutrition, especially as sources of vitamins (Vitamin C, Vitamin A, Vitamin B, thiamine, niacin), minerals, and dietary fibre. Other constituents of fresh fruits and vegetables that may lower the risk of cancer and other diseases include carotenoids, flavonoids, isoflavones, phytosterols, and other phytochemicals (phytonutrients).

* + 1. **Safety factors**

A number of factors threaten the safety of fruits and vegetables. These include naturally occurring toxicants, such as glycoalkaloids in potatoes; natural contaminants, such as fungal toxins (mycotoxins) and bacterial toxins, and heavy metals (cadmium, lead, mercury); environmental pollutants; pesticide residues; and microbial contamination. While health authorities and scientists regard microbial contamination as the number one safety concern, many consumers rank pesticide residues as their most important safety concern.

Unless fertilized with animal and/or human waste or irrigated with water containing such waste, raw fruits and vegetables should normally be free of most human and animal enteric pathogens. Organic fertilizers, such as chicken manure, should be sterilized prior to their application in fruit and vegetable production, so as to avoid the risk of contaminating fresh produce with *Salmonella, Listeria*, and other pathogens.

Commodities that touch the soil are more likely to be contaminated than those that do not come in contact with the soil. The best approach to achieving and maintaining the safety of fresh fruits and vegetables is to focus on limiting potential contamination during their growth, harvesting, handling, treatment, packaging and storage. Strict adherence to Good Agricultural Practices, i.e. basic food safety principles associated with minimizing biological, chemical and physical hazards from the field throughout the distribution chain of fresh fruits and vegetables; Good Hygienic Practices, i.e. conformance to sanitation and hygienic practices to the extent necessary to protect against contamination of food from direct or indirect sources, is strongly recommended to minimize microbial contamination.

Careful handling and washing of all produce to be consumed raw and the strict observance of proper sanitary measures are strongly recommended to reduce microbial contamination at the food-service, retail, and consumer levels.

Table 5.1.Quality components of fresh fruits & vegetables

|  |  |
| --- | --- |
| **Main factor** | **Components** |
| Appearance (visual) | Size, Shape & form, color, Gloss, Defects (Morphological, Physical & mechanical, physiological, pathological & entomological) |
| Texture (Feel) | Firmness, hardness, softness, crispness, succulence, juiciness, mealiness, grittiness, toughness, fibrousness |
| Flavor (Taste & smell) | Sweetness, sourness (acidity), Astringency, bitterness, aroma, off-flavors & odors |
| Nutritive value | Carbohydrates, proteins, lipids, vitamins, minerals |
| Safety | Naturally occurring toxins, contaminants, mycotoxins, microbial contamination |

* 1. **Factors that determine post-harvest quality of harvested products**

Activity 5.2.What are the factors that influence quality?

1. **Genetic factors**

Within each commodity grouping there is a range of genotypic variation in composition, quality, and post-harvest-life potential. Plant breeders have been successful in selecting carrot, sweet potato, and tomato cultivars with comparably high carotenoid levels and vitamin A content; onion and tomato cultivars with longer shelf-lives, sweet corn cultivars that maintain their sweetness longer after harvest; cantaloupe and watermelon cultivars with higher sugar content and firmer flesh, and pineapple cultivars with higher contents of ascorbic acid, carotenoids, and sugars. These are just a few examples of how genetic manipulation has contributed to improving the quality of fruits and vegetables. However, in many cases, commercial cultivars selected for their ability to withstand the rigors of marketing and distribution, tend to lack sufficient sensory quality, in particular flavor.

Horticultural plant breeders have an unprecedented opportunity to address human nutritional needs by developing fruit and vegetable cultivars that are rich in nutrients. In so doing, a multidisciplinary approach should be taken with emphasis the enhancement of nutritional quality for maximum impact on human nutrition and wellness.

Many opportunities exist for applying biotechnology to improving the post-harvest quality and safety of fresh produce. Priority goals in this regard, should, be focused on: (1) attaining and maintaining good flavor and nutritional quality, so as to satisfy consumer demands and (2) introducing resistance to physiological disorders and/or decay-causing pathogens, so as to reduce the use of chemicals on fruits and vegetables.

1. **Environmental factors**

Climatic factors, in particular temperature and light intensity, greatly impact on the nutritional quality of fruits and vegetables. Consequently, the location of production and the season in which plants are grown can determine their ascorbic acid, carotene, riboflavin, thiamine, and flavonoid contents. In general, the lower the light intensity the lower the ascorbic acid content of plant tissues. Temperature influences the uptake and metabolism of mineral nutrients by plants, since transpiration rates increase with increasing temperature. Rainfall affects water supply to the plant, which may influence the composition of the harvested plant part and its susceptibility to mechanical damage and decay during subsequent harvesting and handling operations.

1. **Cultural practices**

Soil type, the rootstock used for fruit tree cultivation, mulching, irrigation, and fertilization influence the water and nutrient supply to the plant, which can in turn affect the nutritional quality of the harvested plant part. The effect of fertilizers on the vitamin content of plants is less important than are the effects of genotype and climatic conditions. The effects of mineral and elemental uptake from fertilizers by plants are, however, significant and variable. Selenium and sulfur uptake for example influence the concentrations of organosulfur compounds in *Allium* and *Brassica* species.

High calcium uptake in fruits has been shown to reduce respiration rates, and ethylene production, to delay ripening, increase firmness, and reduce the incidence of physiological disorders and decay, all of which result in increased post-harvest shelf-life. High nitrogen content on the other hand, is often associated with reduced post-harvest-life due to increased susceptibility to mechanical damage, physiological disorders, and decay. Increasing the nitrogen and/or phosphorus supply to citrus trees results in somewhat reduced acidity and ascorbic acid content in citrus fruits, while increased potassium fertilization results in increased acidity and ascorbic acid content.

Numerous physiological disorders are associated with mineral deficiencies. Bitter pit of apples; blossom-end rot of tomatoes, peppers, and watermelons; cork spot in apples and pears; and red blotch of lemons are all associated with calcium deficiency in these fruits. Boron deficiency results in corking of apples, apricots, and pears; lumpy rind of citrus fruits, and cracking of apricots.

Poor color of stone fruits may be related to iron and/or zinc deficiencies. Excess sodium and/or chloride (due to salinity) results in reduced fruit size and higher soluble solids content.

Severe water stress results in increased sunburn of fruits, irregular ripening of pears, tough and leathery texture in peaches, and incomplete kernel development in nuts. Moderate water stress reduces fruit size and increases soluble solids content, acidity, and ascorbic acid content.

On the other hand, excess water supply to plants results in cracking of fruits (such as cherries, plums, and tomatoes), excessive turgidity leading to increased susceptibility to physical damage (such as oil spotting on citrus fruits), reduced firmness, delayed maturity, and reduced soluble solids content.

Cultural practices such as pruning and thinning determine the crop load and fruit size, which can in turn influence the nutritional composition of fruit. The use of pesticides and growth regulators does not directly influence fruit composition but may indirectly affect it due to delayed or accelerated fruit maturity. Effective pre-harvest disease control greatly influences disease incidence and severity during post-harvest handling of fruits and vegetables.

1. **Maturity at harvest in relation to quality**

Maturity at harvest is the most important determinant of storage-life and final fruit quality. Immature fruit are highly susceptible to shriveling and mechanical damage, and are of inferior flavor quality when ripe. Overripe fruit are likely to become soft and mealy with insipid flavor soon after harvest. Fruit picked either prematurely or too late, are more susceptible to post-harvest physiological disorders than are fruit picked at the proper stage of maturity.

With a few exceptions all fruits attain optimal eating quality when allowed to ripen on the plant. Some fruits are, however, picked at a mature but unripe stage of development so as to allow them to withstand post-harvest handling conditions when shipped over long-distances. Maturity indices for such fruit are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide flexibility in marketing.

Fruit can be divided into two groups: (1) those that are incapable of continuing their ripening process once removed from the plant, and (2) those that can be harvested at the mature stage and allowed to ripen off the plant. Group 1 includes cane berries, cherry, citrus fruits, grape, lychee, pineapple, pomegranate, strawberry, and tamarillo. Group 2 on the other hand, includes apple, apricot, avocado, banana, cherimoya, guava, kiwifruit, mango, nectarine, papaya, passion fruit, pear, peach, persimmon, plum, quince, sapodilla, and sapote.

Fruit of the Group 1 category, produce very small quantities of ethylene and do not respond to ethylene treatment except in terms of de-greening (removal of chlorophyll); these should be picked when fully-ripe, if good flavor quality is to be ensured. Fruit of the Group 2 category on the other hand, produce comparably larger quantities of ethylene which is associated with their ripening, and undergo more rapid and uniform ripening upon exposure to ethylene.

Many vegetables, in particular leafy vegetables, and immature fruit-vegetables (such as cucumbers, sweet corn, green beans, peas, and okras), attain optimum eating-quality prior to reaching full maturity. This often results in delayed harvest, and consequently in produce of low quality.

1. **Method of harvesting in relation to physical damage and uniformity of maturity**

The method of harvesting (hand vs mechanical) can significantly impact upon the composition and post-harvest quality of fruits and vegetables. Mechanical injuries (such as bruising, surface abrasions and cuts) can accelerate loss of water and vitamin C resulting in increased susceptibility to decay-causing pathogens.

Most fresh fruits and vegetables and all flowers are harvested by hand. Root crops (such as carrot, onion, potato, and sweet potato) and some commodities destined for processing (such as processing tomatoes, European plums, and tree nut crops) are mechanically harvested.

Management of harvesting operations, whether manual or mechanical, can have a major impact on the quality of harvested fruits and vegetables. Proper management procedures include selection of optimum time to harvest in relation to product maturity and climatic conditions, training and supervision of workers, and proper implementation of effective quality control. Expedited and careful handling, immediate cooling after harvest, maintenance of optimum temperatures during transit and storage, and effective decay-control procedures are important factors in the successful post-harvest handling of fruits and vegetables.

Attention must be paid to all of these factors, regardless of the method of harvesting used. These factors are nevertheless more critical in the case of mechanically harvested commodities.

**In general there are two types:**

1. Hand harvesting

2. Mechanical harvesting

The method of harvesting is determined by:

1. Nature of the crop, delicacy of crop.

2. The importance of speed during and directly after the harvesting.

3. The cost of labour/machinery.

4. The quality requirements of the market.

5. If it is for fresh consume or for processing.

Mechanical damages that can occur during harvesting:

- Cutting. ex. Potatoes from sharp objects.

- Bruising if falling/hitting

- Compression if overstocking the harvesting boxes

Physical damages can be a gateway for pathological breakdown. Also, respiration and ethylene production will increase if damaged and can lead to physiological breakdown as well.

**Harvest goals**

* **Goals** are to pick produce from the growing area;

a) At the proper maturity stage

b) With minimum damage

c) As rapidly as possible.

* Achievable by manual harvesting (most fruits, vegetables and flower crops) or mechanical.
* Worker training improves harvest quality.

**Manual harvesting**

**Primary Advantages of Manual harvesting**

* Accurate selection for maturity, allowing pre-grading and multiple harvest
* Produce can be handled with minimum damage
* Rate of harvest can be increase as needed by hiring more workers
* Requires minimum capital ( housing may be provided to workers)

**Manual harvesting - disadvantages**

Key problems include;

1. Labour management
	* labour supply (seasonal employment)
	* labour strikes at harvest can be costly

 2. Costs associated with complying with government labour regulations

**Mechanical harvesting**

**Primary advantages include:**

* + - 1. Potential for rapid harvest is available
1. Improved working conditions
2. Reduced problems associated with hiring and managing labour

***Conditions:***

1. Effective use of equipment requires operation by well trained, dependable people.
2. Regular and emergency maintenance must be available.
3. The commodity must be grown to accept mechanical harvest (improved varieties, cultural practices

**Mechanical harvesting - disadvantages**

* Major problems include;
	+ - 1. Damage to perennial crops ( e.g. tree shakers damage barks)
			2. Processing and handling capacity may not be able to handle high harvest rate
			3. Equipment may become obsolete before it is paid for
			4. Social impacts to lower labour requirements.

**Review questions**

1. What is quality for you?
2. Explain how temperature and relative humidity affect quality?
3. Quality versus pre-harvest factors.
4. Differentiate between sweetness, sourness and bitterness?
5. Why do we study about quality standards of horticultural crops?
6. Mention how genetic, cultural and environmental factors affect quality?
7. What are the major quality parameters?

CHAPTER SIX

# Postharvest Damage and Injuries (Stresses)

##  6.1 Stress in relation to postharvest

Stress in general can be any environmental factor that affects the normal development of plants in a negative manner. Stress has effect on the plant itself and the eventual use of the product. From the postharvest perspective, stress is an external factor that will result in undesirable changes in quality. Ability to withstand or recover from stress depends on the amount of reserve energy. Availability of energy, water, and nutrients allows synthesis and presence of different substances like hormones in intact plants but synthesis normally ceased after harvest as a result harvested products are more sensitive to stress.

Potential stresses during postharvest period are: temperature, water, gas, mechanical stress, and pathological problems.

##  Physiological disorders

Physiological disorder refers to the breakdown of tissue that is not caused by pathogens or mechanical damage. The causes of physiological disorder might be temperature, water, and gas composition.

###  6.2.1. Temperature

Both high and low temperatures may cause physiological disorder on harvested products.

**i. High temperature stress**

* The most critical factor which affects both quality and shelf life of the product
* Loss of water through transpiration, loss of evaporative cooling which leads to gradual buildup of temperature in the form of metabolic heat and thermal energy from the air
* **High temperature injuries includes**: inhibition of pigment synthesis; formation of surface burns (sun scaled); surface lesions; failure to ripening in some fruits; desiccation problem; and reduce prolonged existence of the produce.

**ii. Low temperature injury**

* **Chilling injuries**: - Chilling may occur when the storage temperature is about 0 – 120C. For tropical crops, pr**(0C)**oducts can’t tolerate a temperature less than 100C.

Table 6.1. Some product’s critical threshold T0 for storage

|  |  |
| --- | --- |
| Produce  | **Critical threshold temperature for storage**  |
| Banana  | 12 – 13 |
| Mango  | 10 – 13 |
| Cucumber, papaya, egg plant  | 7 |
| Oranges  | 5 |
| Tomato  | 7 – 12 |

Some of the chilling injury symptoms are: surface lesion, surface pitting, wilting, discoloration, browning of the flesh, decay, and inhibition of ripening.

* **Freezing injury: -** For most products, when the storage temperature is at about 00C and below, freezing injury resulted in. When water freezes within the tissue, disruption of the cells occurred and freezing injury will resulted.

### 6.2.2. Water

**i. Loss of water (water deficit)**

Loss of 1 – 2% of water from the product leads to substantial loss of weight, but this loss may be tolerable. However, if the produce loses 5 – 10% of water, for most products it leads to unutilizeability of the produce. Undesirable changes due to water loss include:

* Loss in turgidity and firmness that lead to loss of freshness and quality
* Discoloration of flowers, leafy vegetables, and some fruits
* Loss in flavour and aroma
* Decline in nutritional content (eg., vitamins rapidly disappeared when water loss happened)
* Increased susceptibility to chilling injury and other physiological disorders
* Accelerated aging and senescence

Organs such as onion, potato and fruits lose water gradually and their longevity is relatively longer as compared to leafy crops that lose water rapidly. Some products including seeds, grains, and dates have long shelf life if the water content is very low.

**ii. Excess water**

When the product holds excess water, it allows the growth of moulds that leads to decaying of the product. Moreover, at maximum moisture content, diffusion of gases impaired that affects loss of carbon dioxide and develops more heat.

### Gas composition

During postharvest the concentration of oxygen decreased with the increase in the concentration of carbon dioxide and ethylene. This phenomenon affects the metabolic activities of the produce and the activities of organisms affecting the product quality.

**i. Oxygen**

* **Low oxygen stress**
	+ Will result in pasture effect (anaerobic respiration): formation of undesirable aroma and flavour; altered texture; discoloration; increased incidence of physiological disorders; and change in composition
* Mild oxygen stress
	+ Metabolic activities decreased including decrease in the rate of respiration at slightly above the critical oxygen concentration. This results decrease in:
		- The rate of substrate utilization,
		- Metabolic heat production
		- Rate of softening, weight loss, compositional changes and pigmentation
		- Retard aging
		- Retard the development of physiological disorders
		- The rate of deterioration in quality
* All the above conditions allowed the increase in products prolonged existence.
1. **Carbon dioxide**
* high carbon dioxide concentration effects
	+ Decrease in respiration rate
	+ Decrease in rate of softening
	+ inhibition of chlorophyll synthesis in potatoes stored on direct sunlight
	+ increased in ethylene synthesis
	+ inhibition of some pathogens
* injuries associated with high carbon dioxide concentration are
	+ Increased in incidence of physiological disorders. Example, internal browning in cabbage and discoloration of mushrooms

**iii. Ethylene**

* Effects of high ethylene concentration
	+ Increased in the rate of respiration
	+ Increased in membrane permeability
	+ Alter auxin transport and/or metabolism
	+ Accelerate senescence and deteriorative processes
	+ Loss of quality
		- Change in aroma and flavour. Eg. Carrots become bitter
		- Change in sugar acid composition in climacterics
		- Accelerated rate of degradation of chlorophyll in green tissues. Eg. Cabbage, leaves of many ornamentals
		- Textural changes in climacterics. Eg. Water melons, sweet potato, after cooking
		- Flower colour fading
		- Wilting and closure of leaves
		- Increase in susceptibility to pathogens
* Desirable effects of high ethylene concentration
	+ Used to initiate ripening of fruits
	+ Used to induce selective abscission of leaves, flowers, and fruits
	+ Used to degreening of citrus fruits

## Mechanical injuries

Mechanical injuries are one of the most critical stresses in most harvested horticultural products. Injuries may occur at any point between harvest and consumption periods as a result of

* Poor harvesting practices
* Use of unsuitable containers
* Over and under packing
* Carelessness handling

Injuries may take different shapes

* Splitting of the produce
* Internal bruises/cell rapture
* Scratches
* Crushing of leafy vegetables

Effects of injuries

* Open avenue for microorganisms that cause decaying of the produce
* Increased in loss of water from the produce
* Increased in rate of respiration associated to wounding (to maintain wounding, to response of microorganisms need energy)
* Increased in ethylene synthesis
* Occurrence of internal discoloration due to the entrance of oxygen and oxidation of phenolic compounds
* Development of off flavours
* Defect on the produce even all the above situations doesn’t occur

Susceptibility to injury may vary between

* Species and cultivars
* Degree of hydration
* Stage of maturity
* Product size and weight
* Skin characteristics of the produce
* Environmental conditions particularly temperature and relative humidity

**Response to wounding**

* Injuries may lead to deterioration and death or healing of wounds through production of new cells that require energy. The healing process is accompanied by the: increased in respiration; increased in the synthesis of nucleic acids (RNA), protein and ethylene; and transformation (mobilization) of carbohydrates.
* Response to wounding depends on
	+ age (young meristematic tissues recover quickly)
	+ species and cultivars
	+ temperature, relative humidity and oxygen concentration (environment with warm temperature and high relative humidity is conducive for rapid healing)

**PART II: POSTHARVEST TECHNOLOGY**

* + - 1. **Introduction**

**Postharvest technology** (PHT) is the science which deals with all aspects of quality maintenance, loss reduction, value enhancement and by product utilization of the harvested produce under the condition of optimum energy, economic viability and employment potential. The post-harvest technology programmes could be categorized in to three major groups of activities: food processing, utilization and nutrition; food handling and storage; and design of processes, individual equipment’s, plant system and their testing and adaptation. All these three groups of activities aim at making more and better food available to the people minimizing the loss of food by appropriate postharvest management and increasing the employment potential at rural area level and income of small growers.

The post-harvest technology programmes could be categorized in to three major groups of activities:

1. Food processing, utilization and nutrition;
2. Food handling and storage; and
3. Design of processes, individual equipment’s, plant system and their testing and adaptation.

All these three groups of activities aim at making more and better food available to the people minimizing the loss of food by appropriate postharvest management and increasing the employment potential at rural area level and income of small growers.

**Objective of post harvest technology for horticultural crops:-**

Harvested horticultural crops are living entitles. They carry out vital life processes like transpiration, respiration and others even after harvest when they are harvested and stored, chemical and biochemical changes continue to take place. All fresh horticultural produce must remain alive and healthy until they reach the consumer. The energy that is needed for these life processes comes from the food reserves that accumulated while the commodities were still attached to the plant some of the energy that is produced through respiratory activity is utilized in maintaining life processes. Quality will usually show a gradual decline concurrently with transpiration, respiration and a number of other bio-chemical and physical changes. Eventually, through the action of enzyme activity and or spoilage organism, the plant product reaches a point were it is not acceptable to the consumer. Here, the main objective of post harvest technology is to evolve and apply the appropriate method to arrest this process of gradual decline so that the produce may reach to the consumer in acceptable form.

**1.1 The needs of post harvest technology:-**

The following facts reveal the necessity of post harvest technology

1. The food situation in the world in general and developing countries in particular is of serious concern. The increase in production is off set by the disproportionate increase in population.
2. The basic resources needed to produce more food are diminishing because of
	1. Rapid urbanization
	2. Soil erosion
	3. Higher cost of energy for cultivating crops and producing farm inputs.
3. All that is produced does not reach the consumer as substantial fraction is lost or spoiled.

These lost, spoiled or wasted food represents:-

1. A financial cost (Capital)
	1. A loss of food energy and nutrients
	2. As a loss of return on the inputs of
	3. Labor
	4. Land
	5. Water in its production
2. The modern marketing chain is providing increasing demands of produce and has created the need for post-harvest techniques that allow quality to be retained over an increasingly longer period.

**1.2 Application of post-harvest technology**

Post-harvest technologies may be broadly applied at two levels i.e.

* + 1. At farmers or producers level
1. Pre-harvest management
2. Suitable harvesting
3. Safe handling
4. Grading
5. Pre-cooling
6. Packaging
7. Transportation

for off season availability

1. Storage

For making value added products

Fresh

* + 1. Utilization

Preservation or processing

**1.3 Importance of post harvest technology for horticultural crops**

There is a great importance of post harvest technology for horticultural crops due to the facts that horticultural crops

1. Are highly perishable
	1. Contain high quantity of moisture
	2. Are seasonal
	3. Are delicate in handling

**1.4 Role of post-harvest technology**

The objective of post-harvest technology could only be achieved through judicious application of food engineering and food science principles. PHT can play its role in the following specific tasks.

* 1. Development and promotion of better storage, handling and drying technologies and associated management system.
	2. Development of processes to extend the shelf-life and reduce the loss of perishables.
	3. Improvement of traditional processes to preserve food.
	4. Promotion of food industries
	5. Creation of new employment potential
	6. Increase the sources of income for rural mass.
	7. Identification and development of new processes, equipments and plant systems for value addition through appropriate research/innovation.
	8. Development of technologies for value added products from agro wastes
	9. Standardization of processes, equipments and plant layouts,
	10. Human resource development through formal and informal training programmes

**2. Post-harvest Handling Technologies of Horticultural Crops**

* 1. **Technology of Storage**

Activity 2.1. What will happen if crops are not stored at all?

***What is storage ?***

The storage is the creation of suitable or most congenial condition to increase the availability of the commodity up to maximum possible period and also to create environment that maintains product quality. The desired environment can be obtained in facilities where temperature, air circulation, relative humidity and sometimes atmosphere composition can be controlled.

Purpose of storage:- the followings are the important purposes of storage.

1. For proper marketing of the commodity
2. Balancing day to day fluctuations between harvest and sale.
3. To extend the marketing and availability period.
4. To prolong the usefulness of the commodity.
5. In some cases improves the quality
6. Controls the market glut.

**General points before storage**

 The need for storage

* Most fruit and vegetable productions are seasonal
* Demand is year round- then to ensure continuity of supply

**Storage time depends on**

1. The intrinsic characteristics and perishability of the product

 Shelf life ranges from

* Short e.g raspberries and other berries
* Longer e.g onions, potato, garlic and pumpkin
1. specific product characteristics
* e.g some commodities tolerate temperatures close to 00c such as leafy vegetables
* others such as most tropical fruits cannot tolerate exposure to temperatures below 100c

Not more than one crop should be stored in the same room due to commodity incompatibility. Different crops have differences in:

* Temperature and relative humidity requirement
* Chilling and ethylene sensitivity
* Odor contamination and other problems affecting shelf life and quality

**N.B.** begin with a high quality product (damaged, diseased etc), well ventilated storage facility commodities stored together should be capable of tolerating the same temperature, relative humidity and level of ethylene in the storage.

## 2.1.1 Methods of Storage

**1. In-ground storage:** Pit storage or clamp storage is used for storing hard vegetables e.g. potato, turnip and late season cabbage. They are piled into the pit, which is dug into a hillside or other well drained spot. The pit is lined with hay or straw; the produce is then covered with straw followed by 10 to 20 cm of sods and earth to protect it a gains freezing and rain. Piped ventilation to the outside is provided to avoid the respiratory self-heating. Clamp storage has been suitable only for storage of hard vegetables in cold winter climates and is also suitable for storage of cassava for up to two months in the tropics.

**2. Cellars:** are more sophisticated forms of below-growled storage; they may be part of above ground building or underground rooms, often in hillsides, where access is easier. The performance of cellar is improved by providing controlled ventilation openings for entrance of cold air and exit of warm air by convectional circulation when cooling is required. A good cellar will provide satisfactory storage for hard vegetables and long keeping fruits e.g. apple.

**3. Air-cooled stores**- These are simply insulated structures above ground or partly underground, which are cooled by circulation of colder, outside air. When the temperature of the produce is above the desired level, and if the temperature of the outside air is lower, air is circulated through the stack in the store by convectional or mechanical means through bottom inlet vents and top outlets with dampers. Fans, if fitted, are controlled manually, or automatically which differential thermostats. The air may be humidified, a process that can also be automated. Air-cooled stores are widely used for the storage of potato and sweet potato which need relatively high storage temperature to avoid accumulation of sugar & chilling injury respectively. Potatoes are commonly stored in bulk piles in stores with air delivery ducts under the floor or at floor level, and with suitably spaced air outlets.

**4. Ice - Refrigeration**- The use of natural ice as a refrigerant was an advance on air-cooled storage. The lower temperature obtained by ice refrigeration enabled longer storage of meat & other perishable commodities. Ice was harvested in winter from frozen lakes & ponds and stored in insulated ‘ice houses’. The melting of 1kg of ice absorbs 325 kilojoules, but the considerable bulk of ice needed and disposal of the melted water are disadvantages. The introduction of the small ‘ice box’ or ‘ice chest’ is useful in commercial preservation of perishable foodstuffs.

**5. Mechanical Refrigeration**: James Harrison, (Australian) is the father of modern refrigeration. In 1851 he designed and built a small refrigeration compressor and in 1854 he was granted patent ‘for the production of cold by the evaporation of volatile liquids in vacuum’. A shipment of frozen beef from Australia to England in 1879 was the first successful long distance shipment of perishable which followed by the first mechanically refrigerated cool stores for apple & Pear.

A Refrigeration plant consists of their basic components:

1. **Compressor,** in which the refrigerants gas, either ammonia or halogenated hydrocarbons, is compressed and unavoidably heated.
2. **Condenser** in which the hot gas is cooled and condensed to a liquid, the condenser may be air-cooled or water-cooled.
3. **Evaporator cooling coils** in which the liquid is permitted to boil and so remove heat from its surroundings.

Mechanical refrigeration has two main components: the evaporator, inside the storage area and the condenser which is outside connected by tubing filled with refrigerant. Normally, both elements are finned coils made of high thermal conductivity materials and integrated to a fan. This facilitates heat exchange. An evaporator is placed in the upper part of one of the walls forcing cold air to flow parallel to the ceiling.

Returning air is forced past the evaporator transferring to the coil the heat extracted from the product. A refrigerant absorbs this heat as it changes to gas, cooling the air, which is forced again into the room as cold air. The refrigerant is transported as gas to the condenser where under the pressure provided by a compressor, it is transformed again into the liquid form. The internal heat is then released outside. With this repeated cycle, the system behaves like a pump - heat is extracted from the stored product and then released outside. Another key aspect of the mechanical refrigeration system is the expansion valve, which regulates the evaporation and flow of refrigerant. Ammonia and Freon gas are the most widely used refrigerants. However, they are now being replaced by more environmentally friendly products.

Fans are usually necessary to circulate the storage air over the cooling coils of the evaporator and through the stacks of produce in the store. Moving air is the main agent for transfer of heat from the contents of the store and from leakage into the store, to the coils; radiation and convection may play a small part.

**Factors affecting storage life**

The natural limits to the post-harvest life of all types of fresh produce are severely affected by other biological and environmental conditions:

1. **Temperature**. An increase in temperature causes an increase in the rate of natural breakdown of all produce as food reserves and water content become depleted. The cooling of produce will extend its life by slowing the rate of breakdown.
2. **Water loss**. High temperature and injuries to produce can greatly increase the loss of water from stored produce beyond that unavoidably lost from natural causes. Maximum storage life can be achieved by storing only undamaged produce at the lowest temperature tolerable by the crop.
3. **Mechanical damage**. Damage caused during harvesting and subsequent handling increases the rate of deterioration of produce and renders it liable to attacks by decay organisms. Mechanical damage to root crops will cause heavy losses owing to bacterial decay and must be remedied by curing the roots or tubers before storage.
4. **Decay in storage**. Decay of fresh produce during storage is mostly caused by the infection of mechanical injuries. Furthermore, many fruits and vegetables are attacked by decay organisms which penetrate through natural openings or even through the intact skin. These infections may be established during the growth of the plant in the field but lie dormant until after harvest, often becoming visible only during storage or ripening.
	1. **Cooling Technology**

Required operations before cooling**:**

**Pre-cooling-** The temperature fruits and vegetables at harvest is close to that of ambient air and could be as high as 400C. At this temperature respiration rate is extremely high and **storage** **life** is **short**. Precooling is the rapid reduction of field temperature prior to processing, storage or refrigerant transport. (It is advised to **harvest** early in **morning** as the lower temperature prevails at that time). Quicker the temperature of the produce is reduced to the selected storage temperature the longer will be its storage life. If pre cooling is done timely it helps storage temperature is reach rapidly this reduces loss of energy, reduced losses in stored reserves and reduces losses in quality.

Pre-cooling as a wider term includes any cooling treatment given to produce before shipment, storage or processing but a stricter definition of pre-cooling would include only those cooling methods by which the produce is cooled rapidly and certainly within 24 hours of harvest.

The selection of the pre-cooling method depends on three main factors:

1. The **temperature** of the produce at harvest
2. The **physiology** of the produce
3. The desired post-harvest **life**

In commercial operations, produce is precooled to reach 7/8th of the difference between field temperature and temperature final (temperature required):

T0 final = T0producet – [7x (T0 product -T0 refrigerant)/8

E**.g a product pre cooled with a field temperature of 300c followed by exposure to a refrigerating medium of 100c, should be terminated when 7/8th of the temperature difference is removed. Calculate the final temperature in 0c ??????**

* + 1. **Methods of Pre-cooling**

Commodities may be cooled by means of cold air (room cooling, forced air cooling), cold water (hydro cooling), direct contact with ice and evaporation of water from the produce (evaporative cooling, vacuum cooling).

Activity 2.2 what is need of pre-cooling

**1. Room cooling-** It is the most common cooling method where produce in boxes, cartons, bulk containers or other packages is exposed to cold air in a cool store. For adequate cooling, air velocities around the packages should be at least 60 meters per minute. Room cooling is relatively slow and thus may be inadequate for more sensitive commodity. It removes heat only from the surface of the package, the size and shape of the package being the limiting factor.

**2. Forced air (pressure) cooling**- The rate of cooling with cold air may be significantly increased if the heat transfer surface is enlarged from that of package to the total surfaces of the produce. In forced air cooling, air is forced through the packages and around each piece of produce as a result cooling is faster. It can cool the commodity in about one forth to one tenth of the time required for room cooling. Forced-air cooling is an improved method because cold air is forced through the product. Pallets are lined up in front of a pressure fan and covered with a tarp to form a tunnel. Cold air is pulled

 through the tunnel of covered pallets so the air must go through the containers.

Figure 2.1. Forced air cooling

**3. Hydro-cooling** is a rapid method for cooling in which water acts as the heat transfer medium. It is rapid if the water contacts most of the surface of the produce & is maintained as close to O0C as possible. Dumping produce into cold water, or running cold water over produce, is an efficient way to remove heat, and can serve as a means of cleaning at the same time. In addition, hydro-cooling reduces water loss and wilting. Use of a disinfectant in the water is recommended to reduce the spread of diseases. Hydro-cooling is not appropriate for berries, potatoes to be stored, sweet potatoes, bulb onions, garlic, or other commodities that cannot tolerate wetting. Hydro-cooling provides fast, uniform cooling for some commodities. The commodity as well its packaging materials must be tolerant of wetting, chlorine (used to sanitize the hydro-cooling water) and water beating damage. The simplest version of a hydro-cooler is a tank of cold water in which produce is immersed. The type had shown below showers a batch of produce with icy water as the produce moves along a conveyor. A batch-type hydro-cooler can be constructed to hold entire pallet-loads of produce. Conveyors can be added to help control the time produce stays in contact with the cold water. In many hydro cooling systems, the produce passes under cold showers on a moving conveyor. Hydro cooling may also clean the produce but chances of contamination of the produces with spoilage causing microorganism are also there.

**4. Contact Icing**- Before the advent of some of the modern precooling methods, contact or package icing was used extensibly for precooling the produce & maintaining temperature during transit, especially for highly perishable commodities such as leafy vegetables. Contact icing is now mainly employed as a supplement to other forms of precooling. The finely crushed ice or an ice slurry (liquid ice i.e. 40% water + 60 per cent ice + 0.1 per cent salt) is sprayed on to the top of the load inside the road or rail transit vehicle. This is often referred to as top icing.

**5. Vacuum Cooling** is mostly used for the vegetables that have a high surface to volume ratio such as leafy vegetables. They can be cooled rapidly & uniformly by boiling off some of their water content i.e. moisture at low pressure. The produce is loaded into a sealed container and the pressure is reduced to about 660 Pascals (5mm mercury). At this pressure water boils at 10C and the produce is cooled by evaporation of water from the tissue surface. For every 50C drop in temperature, approximately 1 % of the produce weight is boiled off as water. This weight loss may be minimized by spraying the produce with water either before enclosing it in the vacuum chamber or towards the end of the vacuum cooling operation which is referred as **hydro**.

**6. Evaporative cooling**- In this method, commodity can be cooled by either blowing the humidified cool air or by misting with water and then blowing dry air over the wet fruit. This is a simple process in which dry air is cooled by blowing it across a wet surface. This Method is restricted to regions having climate with low relative humidity but with a good quality water supply. It has the advantage of being low cost cooling method in which dry air is cooled by blowing it across a wet surface. The commodity may be cooled by either the humidified cool air or by misting with water and then blowing fry air over the wet fruit .The extent to which air may be cooled by evaporation of water is limited y the water holding capacity of the air. Evaporative cooling might be considerer suitable for citrus, which do not require very low temperature and grow in dry environment. An evaporative cooler located in the peak of a storage structure can cool an entire room of stored produce such as sweet potatoes or other chilling sensitive crops. The vents for outside air should be located at the base of the building so that cool air is circulated throughout the room before it can exit.

Figure 2.3.Evaporative cooling

**2.3 Pyschrometry**

Pyschrometry: is the study of the properties of air water vapor mixtures or is the study of thermodynamic properties of air and water vapor mixture. Psychrometrics refers to the thermodynamic properties of moist air and the use of these properties to analyze conditions and processes involving moist air. A psychrometric chart graphically illustrates the relationships between air temperature and relative humidity as well as other properties. A better understanding of air properties and the psychrometric chart can aid in the selection and management of a livestock building ventilation system, a grain drying system, or a home humidifier.

**2.3.1 Psychrometrics and Postharvest Operations**

Most of horticultural crops are produced for the fresh market and require proper postharvest control to maintain quality and reduce spoilage. The ambient environment to which the freshly harvested vegetables are exposed has a very significant effect on the postharvest life of these perishable commodities. A better understanding of psychrometrics will allow vegetable producers, packinghouse operators, and commercial cooler operators to improve postharvest cooling and storage conditions for fresh vegetables. This publication presents the relationship of psychrometric variables, considers their effect on perishable commodities, and reviews how they can be measured. This publication further suggests how the psychrometric variables can be used and more importantly how they should be used by managers.

**Common Pyschrometric Paramters**

* Absolute humidity
* Relative humidity
* Dry and wet bulb temperatures
* Dew point temperature

A pyschrometric chart describes the relationship between these parameters.

**Dry bulb temperature**; this is the horizontal line on the chart. It is the temperature measured by the regular (non-wetted) thermometer.

**Absolute humidity or Humidity ratio**: This is the vertical axis on the right side. This refers to the moisture content of the air and is expresses as mass of water vapor per unit mass of dry air. E.g. assume that the outside temp is 8 0C and relative humidity is 85% the absolute humidity of the air can be found to be 0.006 kg water vapor per kg dry air.

**Relative humidity of air**: This is represented by the series of curves shown from 20 to 100. The line 20 refers to a 20% RH curve while line covering 100 represents 100% RH curve. This has no meaning unless it is tied up with another psychrometric variable such as temperature. Mathematically, RH is expressed as a percentage ratio of the water vapor present in the air (PWA) and the saturated vapor pressure (PWs) at that particular temperature. i.e. % RH= (PWA) / (PWs) x 100

**Wet bulb temperature**: It is the temperature registered by a thermometer when its bulb is in dynamic equilibrium with the moisture in the surrounding air.

**Dew point temperature**: is that temperature of the air which when cooled can no longer hold its moisture and hence initiates moisture condensation.

**State point**: A point of the pyschrometric chart determined by any two coordinates. When the state point is known all other properties can be found from the chart.

#### 2.4 Controlled and Modified Atmospheric Storage Technologies

#### The term "storage", as now applied to fresh produce, is almost automatically assumed to mean the holding of fresh fruit and vegetables under controlled conditions. Although this includes the large-scale storage of some major crops, such as potatoes, to meet a regular continuous demand and provide a degree of price stabilization, it also meets the demands of populations of developed countries and of the richer inhabitants of developing countries, providing year-round availability of various local and exotic fruits and vegetables.

In many developing countries, however, where seasonally produced plant foods are held back from sale and released gradually, storage in a controlled environment is not possible because of the cost and the lack of infrastructural development and of maintenance and managerial skills. Even in developed countries, however, there are still many people who, for their own consumption, preserve and store fresh produce by traditional methods.

**2.4.1 Modified atmosphere (MA) storage**

The term modified atmosphere storage is used when the composition of the storage atmosphere is not closely controlled, such as in plastic film packages where the change in the composition of the atmosphere occurs intentionally or unintentionally. MA, the gaseous environment is modified naturally by the interplay among the physiology of the commodities and the physical environment, thus the control of the atmosphere in MA is less precise than CA. In MA, the respiration rate (O2 consumption and CO2 evolution) of the commodity being stored is in equilibrium with the O2 and CO2 concentrations in the surrounding environment.

A more recent term is modified atmosphere packaging (MAP), which related to packages and film box liner with specific properties that offer a measure of control over the composition of the atmosphere around produce. It greatly increase the storage life many of the benefit result of modified atmosphere is storage cannot simply be attributed to reduce in the respiration for *example* under normal experimental condition a 12 fold increase in storage life of green banana can be achieved by ventilating the fruit with an atmosphere comprising 5% CO2 ,3%O2, and 92 N2 in the absence of ethylene ,but respiration measured in terms of oxygen up take is reduce to only one quarter of the rate in air the general storage life is attributed to a reduction in the rate of natural ethylene production by banana & also reduce the sensitivity of the fruit to ethylene. The accumulation of carbon dioxide and depletion of oxygen to beneficial levels by the application of modified atmosphere packaging (MAP) is known to extend the post-harvest life and quality of many horticultural commodities. Indeed MAP has been used also as a supplement or even a substitute for refrigeration to prolong storage life of fresh produce during transportation and retail handling. Furthermore, modified atmosphere packaging (MAP) is an atmosphere control technique that relies on the natural process of respiration of the product and the gas permeability of the package holding the product. Due to respiration, there is a buildup of CO2 and a depletion of O2, and the package material helps to maintain the modified gas levels until the package reaches steady state because of restricted gas permeability. In the steady state condition, the O2 flow entering the package equals the O2 consumed by respiration, and the CO2 flow leaving the package equals the CO2 produced by respiration. Because of the limitation of CA storage to relatively large-scale systems, the MAP technique was developed to provide the optimal atmosphere; not for the entire storage facility, but for just the product, thus maintaining the desired atmosphere during almost all of the post-harvest chain even during the retail display. The MAP can vary from a whole shipping container to a small retail package. As well as the benefits of modifying the O2and CO2levels, MAP has the additional benefits of water loss prevention, product protection, and brand identification. To achieve the desired atmosphere more rapidly, modification of the package atmosphere can be accelerated by using absorbents, or

by using active modification instead of passive modification (i.e., initially replacing the package atmosphere with the desired one by gas flushing). The development of MAP has faced several problems such as

* Lack of commodity respiration data under several temperatures and gas compositions.
* Lack of permeability data for packaging materials at different temperatures and relative humidity.
* Lack of consistency in respiration data gathered for the same commodity.

**2.4.2 Control atmosphere (CA) storage**

In CA, the atmosphere is created artificially and the gas composition is continuously monitored and adjusted to maintain the optimum gas concentration.Controlled atmosphere storage generally refers to decreased oxygen and increased carbon dioxide concentration, and implies precise control of these gases. This storage technique is used to maintain the quality of products by storage in a gas tight container/cold room, where the O2, CO2 concentrations, temperature and relative humidity are controlled. , the system requires sophisticated instruments to monitor the gas levels and is therefore practical only for refrigerated bulk storage or shipment of commodities in large containers. The low O2 conc. in the range normally utilized in controlled atmosphere storage decrease the respiration rate of the tissue, that is 1-3% O2 this effect is pronounced &extremely important for post harvest context.

Factors that have influenced the adoption of controlled or modified atmospheres for commodities include:

* Inherent storage life in air .if the produce can be stored in a satisfactory condition in air for the total marketing period desired. Then there is no need to resort to atmosphere modification to prolong storage life.
* Existence and magnitude of a favorable response to modified produce responds favorably to atmosphere regulation and some produce is little affected.
* Substantial atmosphere tolerance. The beneficial effects of atmosphere modification, especially in modified atmosphere storage, need to be sustained over a relatively wide gas concentration range. A small tolerance range will result in variable quality out turns in commercial usage due to insufficient or excessive gas concentrations.
* Seasonal availability. Use of atmospheres can be advantageous where produce is harvested over a relatively short period in the year. Maximum storage life of such produce is often desirable to extend the marketing period over a greater part of the year.
* Value of the commodity in relation the cost of atmosphere modification. There needs to be a distinct financial gain from the use of atmosphere control.
* Availability of substitute commodities. While produce may be stored satisfactorily in modified atmospheres, it may be more economical to import produce from another region or country that has a different harvest period.

**Beneficial Effects of CA and MA**

Using CA and MA have a wide range of benefits (Kader, 1980; Kader et al., 1989) such as the following:

* The CA and MA conditions reduce the respiration rate (as long as the levels of O2 and CO2 are within those levels the commodity can tolerate and don’t induce anaerobic respiration), which results in delayed ripening and senescence and better maintenance of the quality of the commodity.
* The CA and MA conditions reduce ethylene production and reduce sensitivity to ethylene (action) and this has many beneficial effects such as delaying fruit ripening and tissue senescence, delay of chlorophyll degradation, and maintenance of textural quality (decrease in lignifications, etc.).
* The CA and MA conditions allow handling of chilling sensitive fruits (such as tomato, banana, and mangoes) at temperatures lower than the chilling threshold temperatures in normal air storage.
* Using CA and MA reduces the incidence and severity of some physiological disorders such as the disorders induced by ethylene or by chilling injury.
* Since delaying senescence, including fruit ripening, reduces the susceptibility to pathogens, CA/MA has a beneficial effect in decreasing post-harvest diseases Levels of O2 below 1% and levels of CO2 above 10% can also have a significant direct effect on fungal growth. Carbon dioxide levels above 10-15% (in commodities that tolerate such levels) can be used to provide a fungi static effect.

**Detrimental Effects of CA and MA**

Most CA/MA disadvantages are related to severe reductions of O2 and/or increases in CO2 that force the product into anaerobic respiration (Kader et al., 1989; Brecht, 1980).

Anaerobic respiration causes many disorders such as

* Increased susceptibility to decay and shortening of the storage life.
* Irregular ripening
* Accumulation of ethanol, acetaldehyde, and other compounds that produce off flavors

 and other metabolic dysfunctions.

* Physiological disorders (such as brown stain in lettuce, internal browning and surface pitting in pome fruits).
* Activation of the growth of some anaerobic pathogens that are considered to be major health hazards.

**2.5 Packaging Technology**

Activity 2.3 Mention the advantages of packing products.

Activity 2.4 List the different types of packaging materials and discuss the pros and cons of using these materials?

Packing and packaging materials contribute a significant cost to the produce industry; therefore it is important that packers, shippers, buyers, and consumers have a clear understanding of the wide range of packaging options available. The choice on the types of packaging depends on their functions, uses, and limitations.

How do you rate your packaging materials and the pack size of F & V in Ethiopia? It is our everyday observation that improper packaging materials (leaves, used bags, sacks, etc.), large pack sizes (10, 20, 50, 100 kg), poor transportation (over-load, animal backs, public transport, etc.), lack of care in handling the contents (unprotected produce) and poor storage conditions as the major inputs for post-harvest handling of F & V in Ethiopian local market. Most of these packaging materials, pack sizes, handling and transportation are not to the standard of fresh F & V industry.

#### 2.5.1Packaging requirements for fresh perishable crops

 **The function of packaging or why package produce?**

A significant percentage of produce buyer and consumer complaints may be traced to container failure because of poor design or inappropriate selection and use. A properly designed produce container should contain, protect, and identify the produce, satisfying everyone from grower to consumer.

**a. Containment**

The container must enclose the produce in convenient units for handling and distribution. The produce should fit well inside the container, with little wasted space. Small produce items that are spherical or oblong (such as potatoes, onions, and apples) may be packaged efficiently utilizing a variety of different package shapes and sizes. However, many produce items such as asparagus, berries, or soft fruit may require containers specially designed for that item. Packages of produce commonly handled by hand are usually limited to 22.5 kg (50 pounds). Bulk packages moved by fork lifts may weigh as much as 544 kg (1,200 pounds).

**Packaging Points**

**Recyclability/Biodegradability:** A growing number of many export markets have waste disposal restrictions for packaging materials. In the near future, almost all produce packaging will be recyclable or biodegradable, or both. Many of the largest buyers of fresh produce are also those most concerned about environmental issues.

**Variety:** The trend is toward greater use of bulk packages for processors and wholesale buyers and smaller packages for consumers. There are now more than 1,500 different sizes and styles of produce packages.

**Sales Appeal:** High quality graphics are increasingly being used to boost sales appeal. Multi-color printing, distinctive lettering, and logos are now common.

**Shelf Life:** Modern produce packaging can be custom engineered for each commodity to extend shelf life and reduce waste.

1. **Protection**

The package must protect the produce from **mechanical damage** and **poor** **environmental** **conditions** during handling and distribution. To produce buyers, torn, dented, or collapsed produce packages usually indicate lack of care in handling the contents. Produce **containers** must be strong enough to **resist damage** during **packaging**, **storage**, and **transportation** to market. Because almost all produce packages are palletized, produce containers should have sufficient stacking **strength** to **resist crushing** in a low temperature, high humidity environment. Although the cost of packaging materials has escalated sharply in recent years, poor quality, lightweight containers that are easily damaged by handling or moisture are no longer tolerated by packers or buyers.

Produce destined for **export** **markets** requires that containers to be **extra strong**. Air-freighted produce may require special packing, package sizes, and insulation. Marketers who export fresh produce should consult with freight companies about any special packaging requirements.

Damage resulting from poor environmental control during handling and transit is one of the leading causes of rejected produce and low buyer and consumer satisfaction. Each fresh F & V commodity has its own **requirements** for **temperature**, **humidity**, and environmental **gas composition**. Produce containers should be *produce friendly* - helping to maintain an optimum environment for the longest shelf life. This may include special materials to **slow** the **loss** of **water** from the produce, insulation materials to keep out the heat, or engineered plastic liners that maintain a favorable mix of oxygen and carbon dioxide.

**c. Identification**

The package must **identify** and provide useful information about the **produce**. It is customary (and may be required in some cases) to provide **information** such as the produce **name**, **brand**, **size**, **grade**, **variety**, **net weight**, **count**, **grower**, **shipper**, and country of **origin**. It is also becoming more common to find included on the package, **nutritional** **information**, **recipes**, and other useful information directed specifically at the consumer. In consumer marketing, package appearance has also become an important part of point of sale displays.

Universal Product Codes (UPC or bar codes) may be included as part of the **labeling**. The UPCs used in the food industry consist of a **ten-digit** **machine readable code**. The first five digits are a number assigned to the specific producer (packer or shipper) and the second five digits represent specific product information such as type of produce and size of package. Although no price information is included, UPCs are used more and more by packers, shippers, buyers, and example of UPC retailers as a fast and convenient method of inventory control and cost accounting. Efficient use of UPCs requires coordination with everyone who handles the package.

 **Standardization of packaging**

Produce package standardization is interpreted differently by different groups. The wide variety of package sizes and material combinations is a result of the market responding to demands from many different segments of the produce industry. For example, many of the large-volume buyers of fresh produce are those most concerned with the environment. They demand less packaging and the use of more recyclable and biodegradable materials, yet would also like to have many different sizes of packages for convenience. Packers want to limit the variety of packages they must carry in stock, yet they have driven the trend toward preprinted, individualized containers. Shippers and trucking companies want to standardize sizes so the packages may be better palletized and handled.

Produce buyers are not a homogeneous group. Buyers for grocery chains have different needs than buyers for food service. For grocery items normally sold in bulk, processors want largest size packages that they can handle efficiently - to minimize unpacking time and reduce the cost of handling or disposing of the used containers. Produce managers, on the other hand, want individualized, high quality graphics to entice retail buyers with in-store displays.

Selecting the right container for fresh produce is seldom a matter of personal choice for the packer. For each commodity, the market has unofficial, but nevertheless rigid standards for packaging. Therefore, it is very **risky** to use a **non-standard package**. Packaging technology, market acceptability, and disposal regulations are constantly changing. When choosing a package for fresh fruits and vegetables, packers must consult the market, and in some markets, standard packages may be required by law.

When areas of consumption are far away from the areas of production packaging is required to aid transport and to protect the products. Now with increasing urbanization and increasing international trade, packaging is becoming increasingly important.

The packaging of products are expected to meet a wide range of requirements:

* The packaging material must have sufficient mechanical strength to protect the products during handling and transportation.
* The construction materials must not contain chemicals that can be transported to the products and be toxic to humans.
* The package must meet handling and marketing requirements in terms of weight, size and shape. The current trend is to reduce standard size.

Also mechanical handling makes standardization more important.

Since packages are often handled manually in at least part of the post - harvest chain easy handling sizes, shapes and weights are important. The weights of the packages are important to protect the workers from injuries to their backs etc.

* + - Packages should allow rapid cooling of the contents. i.e. to have ventilation abilities.
		- Packages must withstand climatic factors such as humid and wet conditions.
		- Packages should identify the products.
		- Packages might also be an aid in marketing and retail presentation of the products.

**2.5.2 Packing Materials**

There is a number of packaging materials available:

1. **Natural fiber sacks and bags** - Often not ideal for horticultural crops, but more for cereals and other durable crops.
* **Advantage**: provide good ventilation.
* **Disadvantages:** unprotected from mechanical and environmental damages.
1. Plastic bags: There are different types of plastic bags available.
* **Advantages:** - Easy handling for consumers (last step marketing), it is transparent, Easy for inspecting, suited for MAP (Modified Atmosphere Packaging).
* **Disadvantages:** -May build up water vapor or gasses like O2 and CO2, which can lead to deterioration. It is not environmental friendly. Leave the products unprotected from mechanical damage.
1. **Paper bags**
* **Advantages:** Comparable cheap product.
* **Disadvantages:** unprotected from mechanical and environmental damage (ex.water).
1. **Woven baskets**
* **Advantages**: Good ventilation and relatively cheap.
* **Disadvantages:** Rough surface that can damage soft products. Compression damage if stacked too much. Difficult to keep clean. Difficult to stock, and take more space in storage/transportation.
1. **Wooden field boxes**
* **Advantages:** Relatively durable and reusable.
* **Disadvantages:** may be heavy and expensive. Has rough surface and nails may damage products.
1. **Plastic field boxes**
* **Advantages:** Durable, less heavy than wooden boxes, gives good insulation and has a smooth surface. Has good stacking properties, good water resistance and is easy to clean.
* **Disadvantages:** May be expensive and some may not be heat resistance.
1. **Fiber board boxes** (made of wood pulp or recycled paper)
* **Advantages**: often quite water resistant, durable, less expensive (than plastic) and it is made of by-products of different material (more ecological).
1. **MAP (Modified** atmosphere packing)- Fresh products are packed/wrapped in plastic film. This plastic film restricts transmission of respiratory gasses such as O2 and CO2. Sometimes N2 is injected into the package to balance the internal atmosphere. Especially effective for consumer packages.
* **Advantage:** The products can extend their marketing life.
* **Disadvantage:** Expensive and less controllable for too high CO2 levels and too low O2 levels.
1. **No packaging** Refers to handling of the crop without any container. The crop is transported loose by people, animals and trucks, ex. banana.
* **Advantage:** No cost of packaging material.
* **Disadvantage:** The crop is unprotected from handling damage; it is also exposed to infection, infestation, water loss etc.

**Some examples of packing materials used mainly for export for different products:**

***Onion:***Open weaved natural fiber bags of 25 kg. Earlier standard was large bags of 90 kg, but this is unsuitable both for the heavy weight and the lack of ventilation in these bags.

***Avocado****:* Packed in fiber board or wood trays of 4-6 kg capacity. The fruits are size graded.

***Citrus:***packed into wood or fiberboard containers of 10-15 kg. The fruits are size graded (many countries have automatic size grading).

***Mango:***Packed in single layer trays of 4-5 kg capacity. The fruits are size graded with 8-14 fruits per box.

**2.6 Drying Technology**

All living materials require water for survival. Fresh produce contains up to 95% water and thus is sufficiently moist to support both enzyme activity and growth of micro-organisms. The aim in drying is to reduce the water content of the produce to a level insufficient for enzyme activity or the growth of micro-organisms. The critical level is about 10-15% moisture, depending on the commodity. If too much water is removed, the product becomes brittle and is easily shattered.

Produce can be dried by using solar or artificial heat. Solar (sun) drying is cheap but is not so easily controlled as dehydration by more sophisticated means. Drying by direct exposure to the sun has a number of disadvantages: Exposure of produce to dust and atmospheric contamination; interference from animals and humans; insect infestation; and no control of conditions.

Recently much research has gone into the design of solar driers for fresh produce in order to overcome these problems. Solar driers can be:

The rate of loss of vitamin C from the produce is reduced when the indirect solar drying method is used. Drying should be as rapid as possible in order to maintain quality and minimize vitamin loss. The rate of drying depends on:

* The exposure of a large surface area of the produce, which speeds drying; most produce should be cut into strips not more than 5 mm thick
* The temperature should be high enough (50-700C) to give rapid moisture removal; temperatures over 700C cause discoloration of the product
* The warm air current must be dry; if it is humid, it cannot absorb moisture from the drying product
	1. **Freezing Technology**
* Mechanical refrigeration & of quick-freezing techniques,
	+ The frozen food industry has expanded rapidly
	+ Freezing of foods at homes
	+ Microbial growth is prevented
	+ Action of food enzymes is greatly retarded
	+ Slow rate of a chemical or enzymatic reaction still continue
		- Blanching/scalding before freezing inactivates the enzymes
* The **rate** of **freezing** of food depends upon a number of **factors**
	+ The method employed,
	+ The temperature,
	+ Circulation of air or refrigerant,
	+ Size & shape of package,
	+ Kind of food, etc.
* Freezing is cheaper than canning
	+ Frozen products are of better quality than canned products
	+ **But** storage requires uninterrupted supply of electricity – essential

**A. Preparation of F & V for freezing**

Fruits /vegetables (fully mature)--------washing-----trimming--------cutting in to pieces-------- blanching (Except strawberry which is packed after freezing --------Keeping in syrup or brine ---------- Keeping in syrup or brine----------- Packing-----**Freezing**

**B. Methods of freezing**

There are various methods of freezing:

**1) Sharp freezing (slow freezing)**

* Involves freezing by circulation of air, either naturally or with the aid of fans
* Temperature may vary from -15 to -29°C
* Freezing may take from 3 to 72
* Large ice crystals formed & rupture the cells
	+ thawed tissue cannot regain its original water content

**2) Quick freezing**

* The food attains the temp. of maximum ice crystal formation (0 to -40C) in 30 min or less
* Results in formation of small ice crystals
	+ Minimum disturbance of cell structure
* Most foods are quick frozen by 1 of the following three methods:
1. **By direct immersion**

**Advantages**

1. Perfect contact b/n the refrigerating medium & product;
2. Frozen with a coating of syrup - preserves the color & flavor
3. The frozen product is not a solid block - each piece is separate

 **(b) By indirect contact with refrigerant**

* By contact of the product with a metal surface

 **(c) By air blast freezing**

* Refrigerated air at -18 to -340C is blown across the material

**3) Cryogenic freezing**

* Ultra-fast freezing
* Defined as freezing at very low temperature (below -600C)

**4) Dehydro-freezing**

* Freezing is preceded by partial **dehydration**
* In case of some F & V
	+ 50% of the moisture removed by dehydration prior to freezing
* Improve the quality of the food - more stable

**(5) Freeze-drying**

* Food is first frozen at -180C on trays in a freeze drier
	+ Direct sublimation of the ice takes
	+ The product is highly hygroscopic, excellent in taste & flavor
		- Reconstituted readily
			* Mango pulp, orange juice concentrate, passion fruit juice & guava pulp

**Changes during freezing & storage for frozen products**

* **Quick-freezing** rapidly slows down chemical & enzymatic **reactions** in foods & stops microbial **growth**