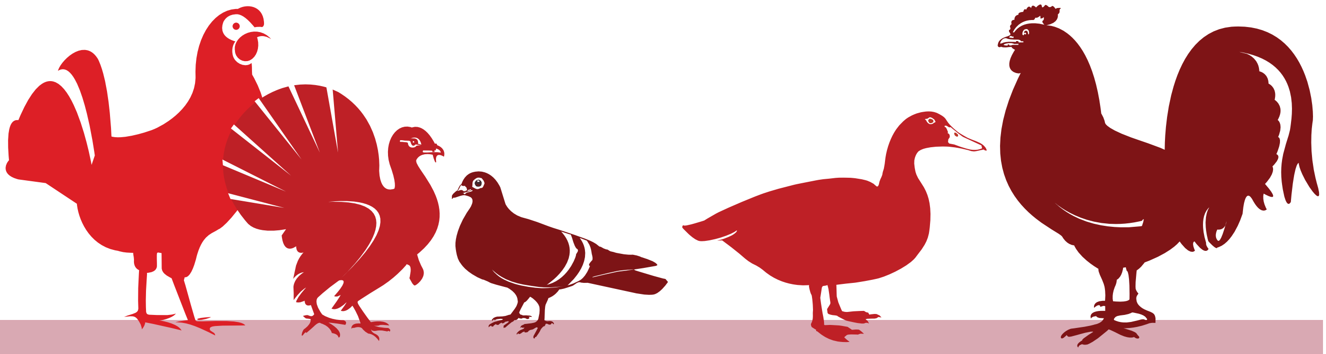

POULTRY DEVELOPMENT REVIEW

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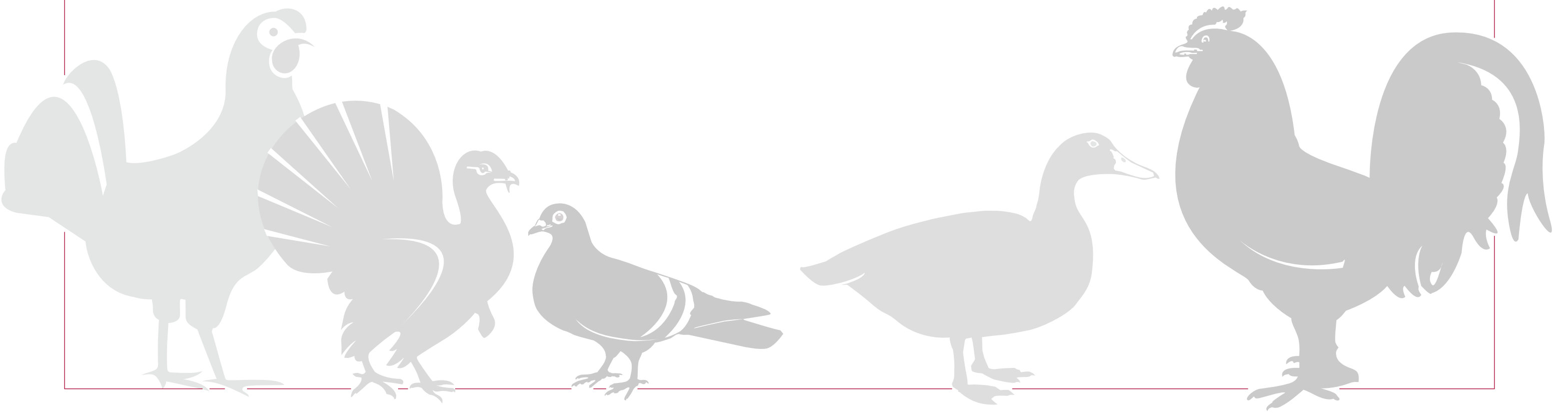
Foreword

The poultry sector is possibly the fastest growing and most flexible of all livestock sectors. Driven primarily by very strong demand it has expanded, consolidated and globalised over the past 15 years in countries of all income levels. Livestock is fundamental to the livelihoods of about one billion of the world's poorest people. Rural poultry, in particular, is essential for the livelihood of many resource-poor farmers often being the only asset they possess. It makes up about 80 percent of poultry stocks in low-income food-deficit countries and significantly contributes to: (i) improving human nutrition, providing food (eggs and meat) with high quality nutrients and micronutrients; (ii) generating a small income and savings, especially for women, thus enhancing the capacity to cope with shocks and reducing economic vulnerability; (iii) providing manure for vegetable garden and crop production. The importance of the socio-cultural and religious functions of village poultry production for smallholder livelihoods, beyond its economic or nutritional importance, is also widely recognized.

This publication is a collection of short articles that give an overview of the benefits of poultry products and information about different aspects of their production. The articles are primarily written to provide information for a general audience rather than for technical experts in the concerned fields of specialization. Originally prepared as separate articles in 2011 for the FAO poultry production website they are compiled in this document for easy access and reference.

The role of poultry in human nutrition



The role of poultry in human nutrition

David Farrell, *School of Land, Crops and Food Sciences, The University of Queensland, St. Lucia 4072, Queensland, Australia*

Chicken meat and eggs are the best source of quality protein, and are badly needed by the many millions of people who live in poverty. In sub-Saharan Africa (SSA) and South Asia malnutrition (poor nutrition) and undernutrition (inadequate nutrition) are closely associated with poverty. These conditions affect the immune system. The HIV/AIDS epidemic sweeping through countries in SSA stems partly from extreme poverty and, with it, poor nutrition.

WIDE VARIATION IN CONSUMPTION OF POULTRY MEAT AND EGGS

A recent survey of several countries found that 34 percent of the people surveyed in South Asia and 59 percent in SSA were suffering from severe energy deficiency (Smith and Wiseman, 2007). Both groups obtained 67 percent of their energy from staple foods (cereal grains, grain legumes, starchy roots and tubers) containing small quantities of only low-quality protein. Their average per capita egg consumption was only 42 per year, compared with a global average of 153. Stunting and wasting in children under five years of age, and slow mental development were seen mainly in rural areas of SSA. Eight out of ten of those affected were among the poor. Diseases such as kwashiorkor and marasmus, both seen in underweight children, are associated with inadequate dietary energy and protein. Pregnant and lactating women and young children are particularly vulnerable.

In SSA, only 8 percent of dietary energy comes from animal protein, compared with an average of 17 percent in all developing countries, and 28 percent in China.

Photo Credit: Flavio Oliveira

Most eggs that are consumed in developing countries are produced by commercial layer breeds

CHICKEN MEAT AND EGGS: A VALUABLE SOURCE OF PROTEIN AND ALMOST ALL OF THE ESSENTIAL NUTRIENTS

Chicken meat and eggs provide not only high-quality protein, but also important vitamins and minerals. Worldwide, 2 billion people depend on rice as their staple food. Most eat polished white rice stripped of many essential fats, the B complex vitamins and several minerals. Other cereal grains are usually deficient in critical nutrients. For example, maize (corn) is a staple food in some regions, but the niacin it contains is unavailable. Maize consumption without supplements causes pellagra. Invariably the protein content of grains is low and of poor quality. Net protein utilization (NPU) is an index of protein quality, calculated by multiplying protein digestibility by biological value. NPU of grains is generally less than 40. Rice is the exception, with NPU of about 60, but it is low in protein (7.5 percent). NPU of chicken eggs is 87. Generally, cereals lack the most important amino acids for humans – lysine, threonine, the sulphur-bearing amino acids (methionine and cysteine) and occasionally tryptophan. Eggs and chicken meat are rich in these essential amino acids.

Eggs are also high in lutein which lowers the risk of cataracts and macular degeneration, particularly among people living in developing countries.

In the least developed countries, the projected increase in egg consumption between 2005 and 2015 is 26 percent, compared with only 2.4 percent in the most developed countries (Windhurst, 2008). Corresponding annual projections for poultry meat are 2.9 percent and 1.6 percent, respectively (FAOSTATS).

ADVANTAGES OF CHICKEN MEAT AND EGGS COMPARED TO OTHER ANIMAL PROTEINS

In developing countries, the diet of people living in cities usually contains more animal protein than that of rural people, mainly because urban people are more prosperous, but also because they generally have access to a wider variety of foods at local markets. In low-income countries, commercially produced chicken meat is well placed to satisfy the demands of a rapidly increasing affluent, middle class who can afford to pay for broiler chickens. Facilities and infrastructure for producing broiler chickens can be established quickly and soon start generating. Not only is chicken meat seen as a healthy meat, but it is also the cheapest of all livestock meats.

A major advantage of eggs and poultry meat as human food is that there are no major taboos on their consumption. In addition, a chicken provides a meal for the average family without the need for a refrigerator to store left-overs. Meat from other livestock such as pigs and cattle is kept mainly for special festive occasions and celebrations, partly because of a lack of storage facilities (no refrigerator or electricity supply). Eggs can be purchased relatively

Photo Credit: FAO

Consumption of duck eggs is popular in Southeast Asian countries

cheaply and in small numbers. One egg is almost a meal in itself and when hard-boiled will last for several weeks. It can be taken to school safely by children for lunch.

SCAVENGING CHICKENS PROVIDE CHEAP EGGS AND MEAT

Scavenging family poultry provide much-needed protein and income, and contribute to food security for many families living in poor rural regions of developing countries. The eggs and meat produced by their own or neighbours' small poultry flocks are the only eggs and poultry meat that the majority of these families are ever likely to eat. This makes family poultry increasingly important as the world's population pushes towards 7 billion people. Furthermore, it is not difficult to improve the nutritional value of the egg, to become a functional food.

CONCLUSIONS

Poultry has a major role to play in developing countries. Produce is relatively inexpensive and widely available. The commercial poultry industry provides employment and is growing rapidly. To produce 1 kg of meat from a commercial broiler chicken only about 1.7 kg of feed is needed. Poultry production has a less detrimental impact on the environment than other livestock, and uses less water. Semi-scavenging backyard indigenous poultry are extremely important in providing income and high-quality protein in the diets of rural people whose traditional foods are typically rich in carbohydrate but low in protein. The vexed question of the cholesterol content of eggs and human health seems to have been exaggerated.

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The nutritional benefits of chicken meat compared with other meats

David Farrell, *School of Land, Crops and Food Sciences, The University of Queensland, St. Lucia 4072, Queensland, Australia*

Chicken meat is a white meat, distinguished from other meats such as beef and lamb by its lower iron content (0.7 mg compared with 2 mg/100 g).

CHICKEN MEAT HAS SEVERAL ADVANTAGES OVER OTHER MEATS

The fat content of cooked chicken varies depending on whether it is cooked with the skin on or off, the portion of the bird, and the bird's diet and breed. Breast meat contains less than 3 g fat/100 g. An average value for dark meat (skin off) is 5 to 7 g/100 g. About half of the fat from chicken meat is made up of the desirable monounsaturated fats, and only one-third of the less healthy saturated fats. There are much higher proportions of saturated fats in most cuts of red meat, which also vary considerably in total fat. Chicken meat is therefore seen as a healthy meat.

Chicken meat does not contain the trans fats that contribute to coronary heart disease, and can be found in high amounts in beef and lamb. In Canada, values of 2 to 5 percent have been reported for beef and as high as 8 percent for lamb. The World Cancer Research Fund and others (Bingham, 2006) have suggested that the consumption of large amounts (more than 500 g/week) of red meat, particularly processed meat, but not chicken meat, may be unhealthy.

POULTRY MEAT IS RICH IN THE OMEGA-3 FATS

Poultry meat is an important provider of the essential polyunsaturated fatty acids (PUFAs), especially the omega (n)-3 fatty acids. Scavenging chickens are a particularly good source because of their varied diet. The amounts of these important fatty acids can be increased more easily in chicken meat than in other livestock meats; so too can some trace minerals and vitamins. The recommended dietary intakes (RDIs) of niacin can be met with 100 g of chicken meat per day for adults and 50 g for infants.

By feeding broiler chickens only small amounts of a supplement rich in alpha linoleic acid (an n-3 PUFA), such as flax seed, the n-3 PUFA in thigh meat can be increased from 86 mg to 283 mg/100 g, and that in the minced carcass from 93 to 400 mg/100 g. To a large extent, the fat contents of the different portions determine the content and enrichment of PUFAs, so dark chicken meat always contains more PUFAs than white breast meat.

POULTRY MEAT CAN BE ENRICHED WITH SEVERAL OF THE IMPORTANT DIETARY NUTRIENTS

Unlike most other meats, chicken meat can also easily be enriched with several other important nutrients. A recent study (Yu *et al.*, 2008) showed that by adding 0.24 mg of selenium (as organic selenium) per kilogram of feed, the selenium content of breast meat was increased from 8.6 µg to 41 µg/100g, which is more than 65 percent of the RDI. The same amount of selenium in the form of inorganic sodium selenite also increased selenium in the breast meat, but only to 16 µg/100g. Selenium deficiency is becoming more widespread in humans because soils are becoming depleted and the foods grown on them are therefore lower in selenium. The RDI of selenium is 55 µg per day. Selenium is a powerful antioxidant and plays a role in the prevention of some forms of cancer. A deficiency of selenium can cause Keshan's disease, a heart ailment in the young, which is common in parts of China, and cognitive decline in adults. Enriched poultry meat could help alleviate this condition.

CONCLUSIONS

Chicken meat can make many positive contributions to the diet of those on low incomes. Although not all meat is seen as healthy, chicken meat is, and is frequently more affordable than other meats. It is of a consistently high quality, is low in saturated fats, can be enriched with some essential nutrients and is sought after worldwide.

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The importance of poultry meat and eggs, especially for children and women

David Farrell, *School of Land, Crops and Food Sciences, The University of Queensland, St. Lucia 4072, Queensland, Australia*

WHY POULTRY MEAT AND EGGS ARE SO IMPORTANT

To illustrate just how important poultry can be in the developing world, this information note examines a typical diet of a three–year-old girl living in Papua New Guinea, weighing about 10 kg and with an energy intake of 4 000 kJ/day. Her diet might consist of a small amount of rice (50 g/day) but mainly sweet potato, taro, yams and cassava. Her family of five keeps a small flock of nine hens and a cockerel. These should produce approximately 12 eggs and one chicken, yielding 780 g of edible meat, each week. This will give each member of the family 22 g of meat a day, and the child receives five of the 12 eggs each week, or 36 g of edible egg per day.

Table 1 shows the daily contribution that the eggs and meat make to the girl's recommended dietary intake (RDI) of some essential nutrients. These are mostly for a child of three to four years of age, but RDIs have not been determined for people living in developing countries and are likely to be generous (by perhaps 20 percent), especially if "the law of diminishing returns" applies to nutrient utilization, so that a low nutrient intake is used with greater efficiency, particularly from animal products.

The eggs and meat will provide the girl with all the critical amino acids and vitamin K she needs, 30 percent of the RDI for folate, 66 percent for vitamin B12, 30 percent for biotin and 29 percent for iodine.

Iron is especially important and often deficient, particularly in the diet of women in developing countries. It is known that the iron in meat and, to a lesser extent eggs, is highly available, unlike the iron in vegetables; the iron in the chicken meat and eggs in Table 1 is likely to meet more than 14 percent of the girl's daily requirement.

TABLE 1

Contributions of nutrients from 22 g/day of chicken meat and 36 g/day of eggs in the diet of a three-year-old girl

	Meat	Eggs	Total	% RDI*
Lysine (mg)	398	310	768	> 100
Meth + cyst (mg)	212	252	464	> 100
Tryptophan (mg)	55	76	131	> 100
Threonine (mg)	194	230	424	> 100
Niacin (mg)	2.0	0.04	2.04	20
Folic acid (µg)	11	34	45	30
B12 (µg)	0.55	0.11	0.66	66
Vitamin K (µg)	12	2	14	> 100
Iodine (µg)	12	14	26	29
Iron (mg)	0.3	0.7	1.0	14
Zinc (mg)	0.3	0.5	0.8	11

* RDI for an infant of three to four years of age, if known, otherwise RDI for an adult.

FOLIC ACID IN POULTRY MEAT AND EGGS IS ESPECIALLY IMPORTANT DURING PREGNANCY

Folic acid deficiency is of major concern in almost all developing countries and has been shown to lead to neural tube defects. These can occur very early in pregnancy, resulting in severe defects of the brain and spinal cord, stillbirths and early child mortality. A recent survey in Uttar Pradesh (India) (Cherian et al., 2005) found that neural tube defects ranged from 3.9 to 8.8 per 1 000 birth – the highest rate in the world. Green leafy vegetables and fruit are good sources of folic acid, but up to half can be lost in cooking. Assuming that she is not a vegetarian, the 45 µg in the meat and eggs shown in Table 1, will provide a pregnant woman with 23 percent of her RDI for folic acid (200 µg/day, although this figure varies widely). The folic acid concentration in eggs can be increased substantially by feeding hens a folic acid-enriched diet.

THE FAMILY ALSO BENEFITS FROM THE DIETARY ADDITION OF MEAT AND EGGS

The family of the infant girl in Table 1 will also benefit through supplementation of their diets with their shares of poultry meat and eggs. Even when only half of the meat and eggs in Table 1 are provided, they will still have a highly beneficial effect on a child by reducing many of the signs associated with a dietary protein deficiency such as low growth, kwashiorkor and poor mental function.

CONCLUSIONS

Poultry meat and eggs are widely available, relatively inexpensive and can be of central importance in helping to meet shortfalls in essential nutrients, particularly of impoverished people. The incidence of several common metabolic diseases associated with deficiencies of critical dietary minerals, vitamins and amino acids can be reduced by the contribution of poultry products rich in all essential nutrients except vitamin C.

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Increasing the nutrient content of chicken eggs to improve human health

David Farrell, *School of Land, Crops and Food Sciences, The University of Queensland, St. Lucia 4072, Queensland, Australia*

Over the past 20 years, there has been considerable interest in chicken eggs as carriers of critical nutrients (Miles, 1998). This has implications for improved nutritional status, particularly of low-income people in developing countries. The technology simply entails increasing the content of some nutrients in hens' diets. Several vitamins (folic acid, B12, vitamin E) can be increased in chicken eggs. Examples of two trace minerals are given in the following.

THE BENEFITS OF INCREASING THE IODINE CONTENT OF THE HEN'S EGG

About 1 billion people, mainly in developing countries, suffer from iodine deficiency, especially in India, Africa and China, often with serious consequences. Iodine has several functions, especially as a component of two hormones (T4 and T3) in the thyroid gland. As a result of iodine insufficiency, slow brain development in the foetus can result in stillbirth or mental retardation in the infant, and in goitre, mainly in adults. Villagers without access to marine food sources and in areas where soils are depleted of iodine are particularly at risk. Vegetables and grains grown on iodine-deficient soils lack iodine, and even when they have the minimum level, much can be lost in cooking. Iodized salt is one long-term solution to this problem. It has been introduced into many provinces in China since 1995, but has not yet reached all provinces.

A hen's egg normally contains about 53 μg iodine/100 g edible portion, which is about 33 percent of the recommended dietary intake (RDI), although this varies. Inexpensive supplementation of a hen's diet with 5 mg of potassium iodide per kilogram of feed does not affect the bird's performance, but increases the iodine content of a 60-g egg from 26 to 88 μg; this is more than 50 percent of an adult's RDI (Röttger *et al.*, 2008).

THE BENEFITS OF INCREASING THE SELENIUM CONTENT OF THE HEN'S EGG

The role of selenium, known to be a potent antioxidant, has recently received considerable attention (Surai and Dvorska, 2001). Selenium is involved in the proper functioning of the immune system and in reducing or inhibiting the progression of HIV to AIDS. This disease is less prevalent in countries where soil has a high selenium content than in countries with a low soil level (Jaques, 2006). Selenium is also required for sperm motility, and may reduce the risk of miscarriage.

The United States Department of Agriculture has allowed the statement, "selenium may reduce the risk of some forms of cancer". It is particularly important in reducing the incidence of prostrate cancer. A deficiency of selenium can have an adverse effect on mood states, especially depression, and may be associated with several other health-related problems, including heart disease (Keshan's disease). The conversion of thyroxine (T4) to the biologically active triiodothyronine (T3) also involves selenium.

One problem with selenium is that, unlike iodine, there are few specific symptoms of deficiency; consequently an obvious deficiency (with few exceptions) has not been recognized, although it may affect general well-being.

Selenium in plants depends very much on soil concentrations. Seafoods are a rich source, as are some livestock products, including eggs and chicken meat. Again, the amount reflects the selenium content of the poultry feed. Because humans' daily intake of selenium is relatively low, eggs are an ideal carrier of the trace mineral; there is a maximum amount that can be transferred from feed, but transfer is efficient at low levels of inclusion. Selenium in the inorganic form is less efficient than in the organic form. Supplementation of a layer's diet with organic selenium at 0.4 mg/kg of feed will increase the content of 100-g of edible egg from 20 μg to about 60 μ g – the minimum RDI of an adult.

CONCLUSIONS

Eggs are an ideal carrier for enriching human diets with some important dietary minerals. The advantages of this approach is that it is unlikely to exceed the minerals' safe upper limits in humans because the amounts sequestered into the eggs are limited, irrespective of the levels in the hens' diet, and quickly reach a plateau.

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The omega-3 fatty acids

David Farrell, *School of Land, Crops and Food Sciences, The University of Queensland, St. Lucia 4072, Queensland, Australia*

TWO GROUPS OF POLYUNSATURATED FATS

There are two families of the polyunsaturated fatty acids (PUFAs) that are essential in human diets: omega (n)-3 fats and omega (n)-6 fats. Linoleic acid (LA), an n-6 fatty acid, is quite common in foods and in most seeds containing vegetable oil, and a LA deficiency is unlikely. Very few plant foods contain the n-3 fats, however, although some oilseeds (rape seed, soybean, walnuts) contain small amounts, while flax seed is rich in alpha-linolenic acid (n-3, ALA), which makes up 22 percent of the oil. Most people living in developing countries are likely to have insufficient n-3 PUFAs in their diet.

The importance of n-3 PUFAs in human health has only recently been recognized. It ranges from protection against some forms of cancer, several specific diseases and conditions (heart disease, brain development, learning ability, and inflammatory diseases such as asthma and rheumatoid arthritis) to general well-being (Anonymous, 2002).

SOME N-3 FATS ARE MORE POTENT THAN OTHERS

To be effective, ALA must first be converted into active forms (eicosapentaenoic acid, [EPA] and docosahexaenoic acid [DHA]) in the body. This is done inefficiently or not at all in the elderly and the very young. Human breastmilk contains significant but variable amounts of EPA and DHA, which can be increased by providing the mother with an n-3 fatty acid-enriched diet to the benefit of the suckling infant. Infant formula, unless supplemented with these fats (which is uncommon in developing countries), contains few or none of them.

THE RATIO OF N-6 TO N-3 IS IMPORTANT

An important feature of these essential fats is the ratio of n-6 to n-3 in the diet. Ideally, this should be less than 4:1 (as in human milk) but in practice it is usually more than 20:1 and probably much higher in developing countries, especially where there may be no access to seafoods, the major source of EPA and DHA. In the human body, this imbalance results in the rapid conversion of linoleic acid into the active form arachidonic acid (n-6), resulting in the production of pro-inflammatory compounds. High levels of linoleic acid elevate thromboxane, which stimulates platelet aggregation, leading to arterial blockage and a possible heart attack.

ELONGATION OF N-3 FATS AND THEIR ENRICHMENT IN EGGS

Chickens have the unusual ability of rapidly converting ALA into DHA in significant quantities, and to EPA in lesser amounts. This means that eggs can be enriched with these important fats, provided that there is an adequate supply of ALA in the hens' diet. The diet of hens usually contains some of the n-3 fats, and 100 g of edible egg typically contains 150 mg of total n-3; of this, DHA + EPA is about 20 mg. By adding 10 percent flax seed (2 percent ALA) to the diet of layers, the total n-3 will rise to more than 600 mg/100 g. About one-third of this will be DHA + EPA. Rape seed oil and rape seeds can also be used to enrich eggs with n-3 PUFAs, but result in lower concentrations. These oil and flax seeds are grown in many developing countries. When included in layer diets, fishmeal, fish waste and fish oil can also increase the n-3 PUFAs in eggs, almost exclusively as EPA and DHA, but if used in too high amounts may cause a fishy taint in the eggs.

HOW MUCH OF THE N-3 FATS DO WE NEED?

Although there is no agreed recommended dietary intake (RDI) for the n-3 fats, some suggest an intake for adults of 2 to 3 g of total n-3 fats per day, of which DHA + EPA should be 0.6 to 0.8 g. An enriched egg can therefore make a significant contribution to these requirements. Requirements for children are not known, but are likely to be considerably less than those suggested for adults. One difficulty is maintaining the critical n-6 to n-3 balance. This normally means reducing the intake of foods containing significant levels of the most commonly used vegetable oils that contain n-6 PUFAs.

CONCLUSIONS

An increasing body of information highlights the importance of the n-3 fats in human health. They are especially important during pregnancy and early infant development. Seafood, the main source of the important EPA and DHA, is becoming expensive, and its consumption is falling. There is generally a severe dietary deficiency of these n-3 fats in both developing and developed countries worldwide, causing a gross imbalance with the n-6 fats and leading to adverse health consequences. The contribution of enriched eggs will become increasingly important, especially to vegetarians, whose diet has only ALA and little or no EPA and DHA.

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How important is cholesterol in eggs?

David Farrell, *School of Land, Crops and Food Sciences, The University of Queensland, St. Lucia 4072, Queensland, Australia*

During the 1990s there was a drastic decline in egg consumption in the developed world. This was due to concerns about the high cholesterol content of eggs, which stemmed from the perceived effects of cholesterol on coronary heart disease (CHD). In fact blood cholesterol level ranks only about fourth or fifth in the risk factors for CHD. Smoking, excessive bodyweight, lack of exercise, hypertension and stress are other important factors, but publicity about the unproven effects of dietary cholesterol on CHD had a major impact on the sale of cholesterol-rich foods, particularly eggs, even though it has been shown that dietary factors may account for only 25 percent of all causes of elevated blood cholesterol (Narahari, 2003).

A 60-g egg contains about 200 mg of cholesterol. The standard daily recommended maximum intake of cholesterol is 300 mg.

IMPORTANT FACTS ABOUT CHOLESTEROL

There are two not widely known facts: i) cholesterol must be in the oxidized (rancid) form to cause the arterial plaques that lead to partial blockage of the blood vessels; and ii) some forms of cholesterol are beneficial. High-density lipoprotein cholesterol (HDL) protects against heart disease by mopping up circulating cholesterol. The culprit is the low-density lipoprotein cholesterol (LDL) in the oxidized form that narrows or "hardens" the arteries. One way of counteracting this process is therefore to eat foods rich in natural antioxidants.

A third important point is that the fat in eggs is in the unusual form of emulsified oil, almost half of which is made up of healthy monounsaturated fats. This combination probably minimizes the effect of eggs on blood cholesterol.

Cholesterol is not a dietary requirement although it is found in almost every cell in the body, particularly in the brain and nervous tissue. The liver produces up to 2 000 mg per day. Only about 50 percent of dietary cholesterol is absorbed, while the rest is excreted.

INDIVIDUALS MAY RESPOND DIFFERENTLY TO DIETARY CHOLESTEROL

Not everyone responds to dietary cholesterol. There are hypo- and hyper-responders (85 and 15 percent of the population respectively). In one experiment (Elkin, 2006), men and women were given 21 eggs per person per week, amounting to about 640 mg of cholesterol per day. Plasma LDL did not change in the hypo-responders; in the hyper-responder group it increased by a small but statistically significant amount (10 to 15 mg/dL). Given the unrealistically high consumption of eggs in this study (three per day), it is surprising that the hypo-responder group did not also show an increase in LDL cholesterol.

REDUCING BLOOD CHOLESTEROL WITH DRUGS

Statins are a group of drugs that inhibit the enzyme HMG-CoA reductase from converting HMG-CoA into mevalonate – an early step in the synthesis of cholesterol. Given the very wide functions of cholesterol, this could be thought to be a retrograde step, but apparently it is not. Consequently, statins frequently account for a very large share of drug sales, as they are routinely prescribed even for people with only mildly elevated cholesterol, who then often stay on them for life.

CAN EGG CHOLESTEROL BE REDUCED?

Attempts have been made to lower the cholesterol in eggs (Elkin, 2007) by feeding different grains to layers, which may reduce egg cholesterol by about 10 percent. Feeding copper at 125 or 250 parts per million (ppm) can reduce cholesterol in eggs by up to 31 percent. Feeding garlic as a paste at up to 8 percent of the diet may reduce egg cholesterol by as much as 24 percent, but there is wide variation. Other natural products have also shown significant but inconsistent responses. Genetic selection for low and high egg cholesterol has met with little success. Although the cholesterol content of the egg is well in excess of that needed for embryo development, reducing egg cholesterol beyond a certain point can decrease hatchability and/or egg production.

CAN WE REDUCE ABSORPTION OF CHOLESTEROL IN FOOD?

Excess cholesterol is removed from the liver as HDL cholesterol, or largely converted into bile salts, then passed into the ileum, absorbed back into the blood stream and returned to the liver. Some continues to the colon and is excreted as bile acids. Compounds such as insoluble dietary fibre and saponins, found in plants (especially the yucca tree), can bind cholesterol in the small intestine, causing it to be excreted. Fibre also increases the rate of food passage, thereby reducing the opportunity to recycle cholesterol via the lower ileum.

HOW MANY EGGS SHOULD WE EAT?

Nearly half (45 percent) of the public in the United Kingdom still believe that they should be eating a maximum of three eggs a week. A recent article in the British Nutrition Foundation's *Nutrition Bulletin* (2009, 34(1): 66–70) reveals that misconceptions about eggs and cholesterol stem largely from incorrect conclusions drawn from early research.

Many heart and lung health organizations have done a complete turn-about and some have even given eggs the "heart tick" of approval. Although the recommendation of 300 mg of cholesterol per day as the upper level still stands, there is general consensus that one egg a day will do no harm – not that the cholesterol content of the egg has changed in the meantime.

Many nutrition and health advisory bodies may have been influenced by several recent scientific papers, which have dispelled myths around eggs and cholesterol. Australian, Canadian and Irish heart foundations and the British Nutrition Foundation have raised their guideline limits in accordance with recent findings that there is no conclusive evidence to link egg consumption with an increased risk of heart disease.

PUBLIC PERCEPTION OF EGGS IS DIFFICULT TO CHANGE

Concern about a link between cholesterol in eggs and risk factors for heart disease is difficult to dispel. Many people living in developing countries still believe in the dangers of eating eggs, even though they would be the least at risk. Except for the few most affluent people, the staple diet in developing countries is mainly plant-based and contains only small amounts of cholesterol.

CONCLUSIONS

Consumption of one egg per day will have no effect on blood cholesterol; recent research suggests that two per day will also have no significant effect for most of the population. The conclusion is that eggs are not detrimental to human health and that for those in low- income countries, eggs are very important for good health and well-being, and their consumption should be encouraged.

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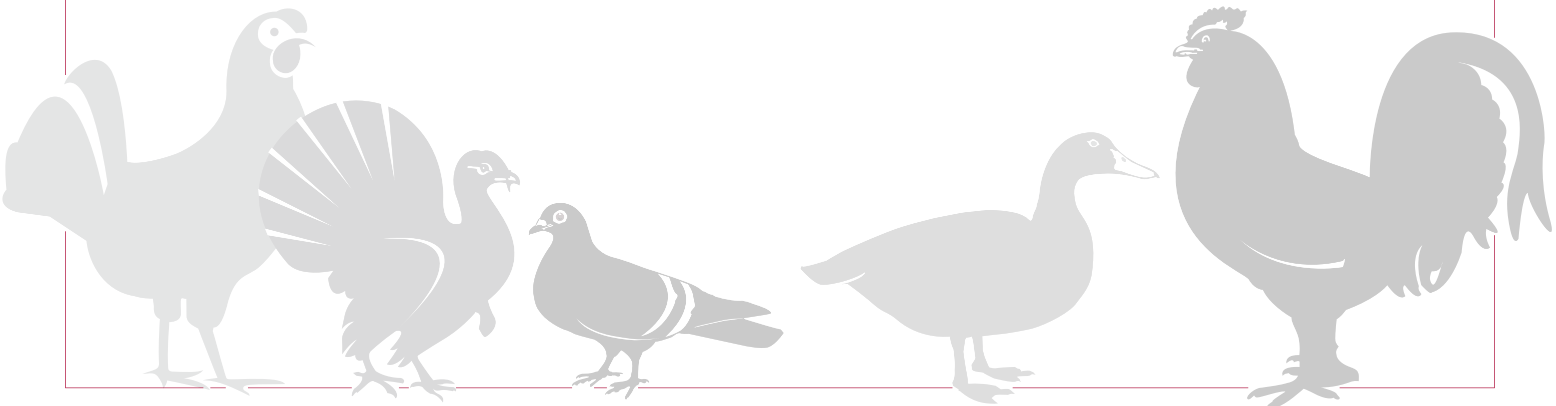
Poultry and poultry products - risks for human health



Consumption

Marisa Ventura da Silva*, DVM, independent consultant, The Netherlands*[1]

INTRODUCTION

Unless all the necessary precautions are taken along the poultry production, marketing and processing chains, poultry meat and eggs can be contaminated by infectious agents that are harmful to humans. Poultry products can also be contaminated with the antimicrobial and anti-parasitic drugs or pesticides used on farms. The ingestion of antimicrobials can cause antimicrobial-resistant bacteria to develop in humans.

Campylobacter and *Salmonella* infections are among the most important food safety hazards. These bacteria account for more than 90 percent of all reported cases of bacteria-related food poisonings worldwide. Most of these cases are related to the consumption of poultry and poultry products, but all domestic livestock are potential reservoirs of infection. Reported cases of *Campylobacter* and *Salmonella* infections are believed to represent only a fraction of the true number of cases.

Consuming raw or undercooked poultry or poultry products has been implicated as a potential risk factor for human cases of influenza H5N1 infection (HPAI). Poultry meat should be well cooked, with the core temperature reaching 70°C for at least one second during cooking.

Data on food-borne diseases in low-income countries are scarce. There is no precise and consistent global information about the full extent of the occurrence of food poisoning and the costs related to unsafe food. Symptoms are often mild and cases are not reported, but their importance is thought to be substantial.

RISK FOR CONSUMERS

In many countries, eating habits have undergone major changes over the last two decades. The middle class is growing, and this group of people eats more meat and goes out more often for meals. Migration from rural to urban areas has also resulted in changed eating patterns. New food production, preparation and distribution techniques have developed in response to these changes. There is a large increase in "fast food" and other ready-to-eat foods, which means that consumers have less control on the selection, preparation and storage of the meat they consume.

Children and people in stress situations, such as those facing malnutrition, war or natural disasters, are especially at risk of food-borne bacterial diseases. The main symptom is diarrhoea, and infection can be fatal (with 0.01 percent mortality in infected people in high-income countries). As the causal agent is a bacterium, these diseases can be treated by antibiotics, but access to treatment is difficult in many low-income countries. Another problem is the development of resistance to antibiotics among zoonotic bacteria.

PRODUCTION SYSTEMS

Backyard poultry production is an important activity for many rural households. Consumption of meat and eggs from this production system is considered safe because of the habits usually observed among consumers purchasing or preparing birds from backyard poultry production. Preparation is usually just after slaughter. Because a chicken provides one meal for a family, there are usually no leftovers. The meat is thoroughly cooked, which reduces the risk associated with the consumption of sick birds that is observed in many poor rural areas. If birds are infected, there is risk of human infection with pathogens during the handling of live birds and during preparation.

People with little or no experience of poultry farming may invest in smallholder intensive poultry production and may build a small broiler or layer chicken house, often near new settlements or suburbs. In these small-scale operations, the use of antibiotics – which is sometimes adopted to compensate for poor performance resulting from inexperience in management – is not adequate. The risk of consumers ingesting antimicrobials and/or antibiotics is particularly important.

In general, poultry meat and egg products from large-scale commercial operations are subject to efficient control processes and are safe. Large companies normally take considerable care to avoid bad publicity resulting from the commercialization of unsafe food products. However, one of the most common problems for large-scale commercially produced poultry meat in low-income countries is the lack of refrigeration during marketing. Table 1 gives an overview of risk factors for food-borne diseases related to the consumption of poultry and poultry products from production systems in low-income countries.

REDUCING RISKS

The appearance of clinical signs in infected humans, and the importance of these signs will depend on several factors. On a chilled carcass taken out of the refrigerator, most bacteria need an adaptation time of about two hours before they start to multiply. Usually, only high numbers of bacteria will cause disease, and only in more vulnerable people. Consumers can reduce the risk of bacterial food-borne diseases by refrigerating the meat from the moment it is bought until the moment of preparation (heating)

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[1] With contributions from Philippe Ankers, FAO

TABLE 1

Quality control and risk factors in low-income countries

Characteristics	**Production system**		
	Backyard	**Smallholder intensive**	**Industrialized**
Production chain	Short	Medium	Long
Quality control during production	-	±	+++
Quality control during slaughter	-	±	+++
Product	Live birds	Live or locally slaughtered birds	Frozen parts, defrosted at the market
Contact between consumer and live product	+++	++ in live-bird markets or poultry shops	-
Refrigeration chain	Not necessary, immediate preparation of whole carcass	Often not available	Often interrupted because of long chain
Consumer risk from bacterial contamination	+	++	+++ if refrigeration chain is broken
Consumer risk from resistant bacteria	-	+	+
Consumer risk from veterinary drugs residues and pesticides residues	-	+++	-

+ = present; - = absent

for consumption. Temperature and cooking time are critical in minimizing risk. Contaminated parts are less likely to cause food poisoning problems if the meat is well cooked. However, some bacterial toxins are heat-stable, and will not be deactivated. Proper attention to minimizing bacterial contamination and proliferation is required from slaughter until cooking. Coagulated blood, blood pudding and chicken-and-duck blood soup can contain harmful pathogens if not well cooked.

The World Health Organization (WHO) has elaborated the Five Keys to Safer Food programme (http://www.who.int/foodsafety/consumer/5keys/en/). Messages for food handlers and consumers have been developed, to decrease the incidence of food-borne diseases. Educational and training tools have also been developed. Education is an important measure for preventing risks to human health from poultry products.

Knowledge = prevention!

Thoroughly cooking in stew pans is fairly common in developing countries. The widely practised habit of washing the skin or cutting the surface of the poultry meat before cooking helps to reduce bacterial contamination.

Photo Credit: Centre For Livestock and Agriculture Development (Celagrid)

Coagulated blood for consumption

CONSUMER PROTECTION

The pattern of food-borne disease outbreaks has changed during the last two decades. In the past, most outbreaks were acute and localized, and resulted from a high level of contamination. Now, more outbreaks affect several countries at once, resulting from low-level contamination of widely distributed commercial food products. Risks of the contamination of poultry products by residues and bacteria exist everywhere, owing to the globalization of poultry production and trade. Counteracting this, the relative risk of contaminated poultry products reaching the market has reduced in the last decade, thanks to faster and more reliable diagnostic tools, the establishment of a world epidemiological alert system, and overall improvement of hygiene standards. The availability of efficient antibiotic treatments has also reduced the impact of food-borne diseases.

As most food safety hazards related to poultry come from the immediate health risks of ingesting foods contaminated with zoonotic bacteria, regulation and testing efforts have focused on reducing the incidence of this type of contamination. Over recent decades, the food chain approach has been recognized as a valuable step forward in ensuring food safety from production to consumption. Such a system can also control contamination with pesticides and veterinary drugs along the production and marketing chains.

The many and varied routes of contamination mean that many actors have a role in reducing risk, including feed mill operators, farmers, chicken processors, retailers, supermarkets, restaurants, takeaway establishments, health authorities, legislators, governments and consumers.

Flock health, the structure of the poultry food chain (short or chilled), the quality of control procedures during production and supply processes and on the final product – all contribute to the marketing of safe poultry meat and eggs.

WHO has set up a Food-borne Disease Burden Epidemiology Reference Group (FERG), which harmonizes international efforts to estimate and reduce the global importance of food-borne diseases. This will help countries to estimate the magnitude of food-borne illnesses and to evaluate progress in their control. FERG will provide initial estimates of the importance of food-borne diseases worldwide by 2012. An international network of laboratories, alert systems and collaboration among authorities assist in solving food safety problems.

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Marketing

Marisa Ventura da Silva*, DVM, independent consultant, The Netherlands*[1]

INTRODUCTION

Since the 1990s, the production of poultry meat in low- and middle-income countries is increasing, with chicken meat accounting for 80 percent, and duck and goose meat production also increasing. China and Brazil, in particular, have emerged as major poultry meat producers. Meanwhile North American and European producers have lost their global market shares. Over the last 30 years, egg production has also increased enormously in East and Southeast Asia. In 2007, about 45 percent of the eggs consumed worldwide were produced in China (FAO, 2009).

INTERNATIONAL TRADE

In most countries, poultry production is mainly for domestic consumption. According to FAOSTAT, only about 12 percent of poultry meat and 2 percent of eggs were traded on the world market in 2007. However international trade is increasing. Brazil and the United States are the two largest exporters of poultry meat. Global trade in poultry meat and meat products involving processing is complex.

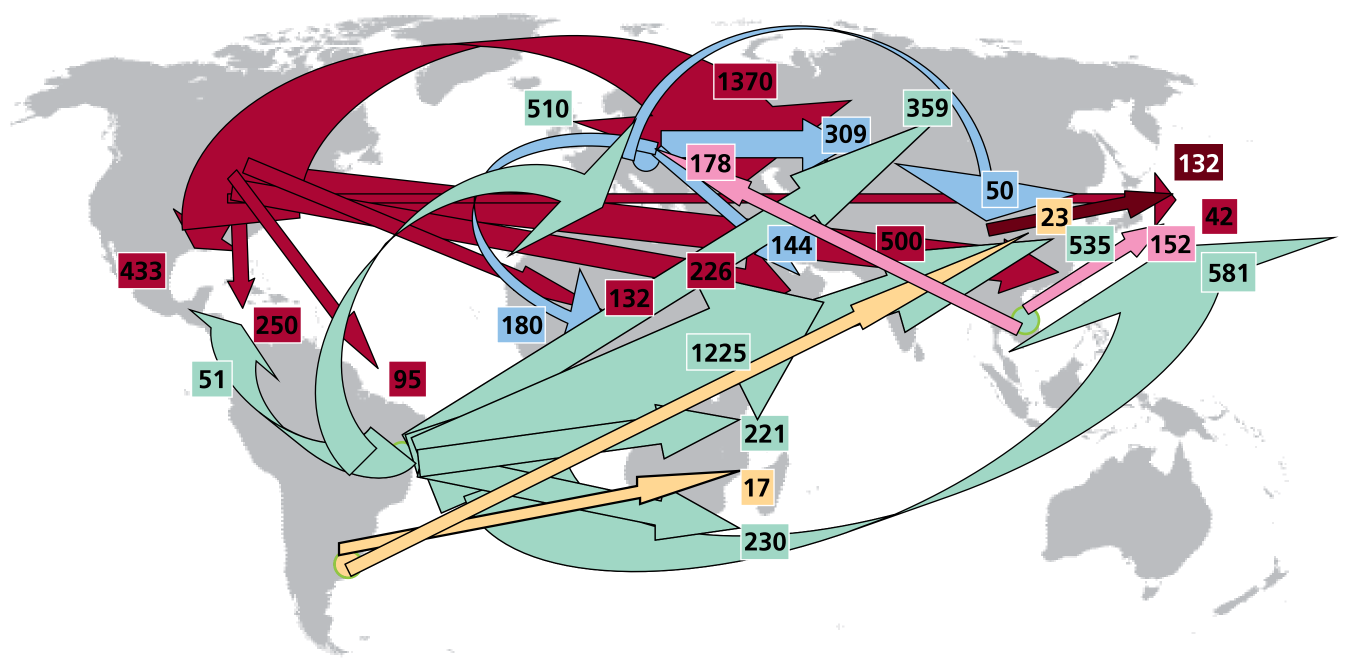
Most of the poultry meat available on the global market comes from large-scale specialized commercial poultry production systems. In low-income countries, imports of cheap low-quality cuts such as wings, lower legs, necks and giblets sold by the piece, make chicken meat more accessible to the average consumer. This coincides with changing eating habits in developed countries, where consumers tend to buy chicken breast and thigh meat and, to a lesser extent, drumsticks. Poultry meat products are usually exported frozen.

In many low-income countries, particularly those with tropical climates, trade in frozen food entails risks. It is not uncommon to see defrosted poultry meat displayed for sale on open market stalls without refrigeration, which presents a risk to human health. The smaller the pieces, the higher the risk of contamination, owing to the increased surface area. Carcasses or cut-up pieces must remain frozen throughout the marketing chain.

When the refrigeration chain is interrupted, infectious agents start to multiply on the meat. The consumption of contaminated meat can cause diseases, especially if the meat is not well cooked.

FIGURE 1

Poultry meat and meat product imports and exports 2008, including live birds ('000 tonnes carcass weight equivalent)



Source: Gira Meat Club.

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[1] With contributions from Philippe Ankers, FAO

Photo Credit: Association Citoyenne de Défense des Intérêts Collectifs (ACDIC)

Frozen chicken pieces displayed at markets are a health risk for the population

Appropriate control of the refrigeration chain is therefore required, from port, to market, to consumer.

If other food, such as salad, comes into contact with raw contaminated poultry meat, it too can be contaminated and will be dangerous to health when eaten raw. Cross-contamination during food preparation is another important risk factor.

In countries where H5N1 highly pathogenic avian influenza (HPAI) is reported, poultry meat can be exported only as processed products (cooked, pasteurized) to avoid spread of the virus to other countries. In frozen poultry meat products Influenza viruses are not killed by refrigeration or freezing, but human cases of influenza H5N1 infection are mainly the results of direct contact with live birds (Swayne and Thomas, 2008).

Bacteria, such as *Salmonellae*, which cause Salmonellosis in people, also survive in frozen products, and can become harmful when they start multiplying after defrosting. Antimicrobial-resistant bacteria can also be disseminated through trade of poultry meat products.

INTERNATIONAL FOOD SAFETY STANDARDS

For World Trade Organization (WTO) member countries, the Sanitary and Phytosanitary (SPS) Agreement defines the basic rules for food safety and animal and plant health standards. It allows countries to set their own standards, but these must be based on science. The Codex Alimentarius is a collection of international food safety standards that have been adopted by the Codex Alimentarius Commission (the Codex), which was jointly set up by FAO and the World Health Organization (WHO). Under the SPS Agreement, the Codex is the relevant standard-setting organization for food safety. The Codex Alimentarius includes food safety standards related to poultry meat and eggs. Harmonizing application of the CODEX standards among countries is a challenge. Consumers' perceptions of the risk related to food consumption differ among countries, as do the availability of market information, the importance of risk factors at the farm level, and the standards for food processing and packaging technologies. The benefits of applying a specific food safety standard may exceed the costs in some countries, and various food safety risk control measures can achieve similar results. As risks for food safety vary among countries, the identification of risk factors for each poultry product is a first step in risk control, as described in the CODEX.

LOCAL TRADE

In many low-income countries, local chickens are traditionally sold alive at live poultry markets (also called "wet markets"), where slaughtered birds or poultry meat can also be purchased. Live-bird markets are considered critical risk points for the spread of the H5N1 HPAI and other viruses. Authorities may decide to close these markets when there are outbreaks in the area, region or country. In the medium to long term, authorities will encourage the purchase of poultry meat that has gone through a certification process. Contact between people, especially children, and live poultry bought at the market should be discouraged.

OUTLOOK

Global demand for poultry and poultry products will continue to increase, owing to global population increase and growing per capita consumption. Trade will also go up, facilitated by improvements in transportation, infrastructure and marketing networks. These factors, and the rapidly changing regulations and rising standards for food safety in high-income countries, create both challenges and opportunities for low- and middle-income countries.

For many years, intensive poultry production units in high-income countries have approached risk management by focusing first on risk identification and then using Hazard Analysis Critical Control Points (HACCP) procedures. This approach is now adopted by producers in low- and middle-income exporting countries as well. The Codex committees provide advice on the introduction of such procedures. Regulatory agencies worldwide are also increasingly adopting the HACCP procedures as a foundation for new regulations to control microbial pathogens in food. Based on risk assessment, critical control points are identified in the production chain, and adjustments in the chain will ensure the quality of final products.

Governments and the private sector must join forces to improve capacity to react quickly to emerging food safety crises, thereby minimizing human illness and financial losses.

An increasing number of low- and middle-income countries are exporting poultry and poultry products, and the adoption of international standards for food safety is essential. Brazil's remarka-

Photo Credit: Centre For Livestock and Agriculture Development (Celagrid)

Live-bird market in Asia

ble development as a major chicken meat exporter was facilitated by the adoption of strict food safety regulations, and provides an example for neighbouring countries.

Poultry export control systems are self-financing. Certification is mandatory in this profitable business. The private sector usually pays for these controls, but government official services and a product board are sometimes involved in carrying them out. Public health and veterinary services must be involved, ideally together, in controlling the entire marketing system within the country, from large-scale integrated operations, down to live-bird markets and small slaughter shops, where they exist.

The refrigeration chain for poultry meat is a key factor in food safety, and must be guaranteed by a system in which certificates are required to permit the sale of products. An example of this is the implementation of minimum hygiene criteria for street sellers. In small-scale production systems, only the government can undertake such control, for economic reasons. It requires support from strong legislation and enforcement to prevent false competition.

The protection of human health during H5N1 HPAI outbreaks is also a responsibility of government. Government has all the centralized information about the spread of the disease, and can – under certain circumstances – prohibit the operation of live-bird markets and indicate other safe sources of poultry meat.

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Slaughtering and processing

Marisa Ventura da Silva*, DVM, independent consultant, The Netherlands*[1]

INTRODUCTION

Handling of live birds brings perhaps the greatest risk of exposure to viruses for farmers, their families and poultry workers in areas where highly pathogenic avian influenza (HPAI) is present. A study in Guangzhou, China in 2007 to 2008 found that 15 percent of poultry workers in live poultry markets, where the birds are also slaughtered, had antibodies against HPAI. This compares with only 1 percent in the general population (Wang, Fu and Zheng, 2009).

However, there are also risks of human exposure to pathogens originating from the poultry slaughtering, processing, storage, handling and preparation phases. Poultry can be contaminated with harmful infectious agents, and raw poultry products are reported to be responsible for a significant number of cases of human food poisoning.

During these phases, controlling the contamination of carcasses by such pathogens presents a considerable challenge, especially in small-scale operations. In tropical countries, the ambient temperature is usually above 20°C, with a high degree of humidity creating favourable conditions for the multiplication of most bacteria. During the hot season, increased numbers of bacteria are found on poultry carcasses.

To quantify the food safety risks along the production and marketing chain, it is important to know how, where and when contamination with microorganisms occurs. Once this is known, it is possible to introduce risk reduction measures. The adoption of improved technology and strict hygiene measures can often reduce the risk of contamination of carcasses. The slaughtering facility must be divided into at least three separate sections: a live birds' area; a slaughtering area, including defeathering; and a processing area, starting with evisceration. To reduce the risk of pathogens multiplying on carcasses, poultry meat and carcasses should be refrigerated or consumed immediately after slaughter.

The native microflora of processed poultry is composed of many types of bacteria and yeasts, most of which are part of the microflora of live poultry. This microflora is carried into the processing facility on the body and in the intestines of the birds. For example, the bacteria *Campylobacter* spp. and *Salmonella* spp. inhabit the intestines of healthy birds, and can cause disease in humans, depending on their pathogenicity and the number and concentration of bacteria on the product. The sum of these factors will determine whether the consumer is at risk at the time of consumption.

The cleaner the birds are when they arrive at the slaughter place, the fewer the bacteria on their carcasses during slaughtering. On many farms, it is difficult to achieve low bacterial counts on the skin and feathers of birds, so emphasis should be placed on hygiene at the slaughter line.

LARGE-SCALE COMMERCIAL SLAUGHTERHOUSES

In modern large-scale slaughter plants, appropriate equipment is used and there are strict procedures for minimizing contamination. Nearly all procedures are automatic, and birds' contact with surfaces or poultry workers is kept to a minimum; for example, the carcasses are scalded in a counter-flow system, with the water flowing from clean to dirty, in the opposite direction to the birds. Automation enables the efficient control of hygiene, residues, etc. Although control systems are expensive, the large scale of operations means that this expense will have only a marginal effect on the prices of final products. These technical solutions and controls ensure delivery of a very safe product. If the processed carcasses are kept refrigerated and delivered rapidly to the supermarket, and kept there under appropriate temperatures, the consumer can be assured of buying a safe poultry product.

SMALL-SCALE SLAUGHTERING FACILITIES

In small-scale slaughtering facilities, birds are killed and then scalded in hot water. The carcasses are then plucked and eviscerated, mostly by hand. Before and after evisceration, carcasses are often washed, which may contribute to the dissemination of bacteria on and among carcasses. Further down the marketing chain, trussed birds are often displayed on shelves at ambient temperatures until they are sold. Unsold birds may be put into a refrigerator overnight.

When ambient temperatures are moderate to high (above 20°C) the microorganisms will multiply quickly, resulting in rapid deterioration of the meat's quality and safety, if the products are not cold-stored.

Traditional slaughtering during the hot season has been found to result in a significantly increased incidence of bacterial flora on poultry carcasses (Cohen et al., 2007). When carcasses are properly cooled (at 4 to 10°C), the growth of pathogens slows down.

REDUCING CONTAMINATION OF POULTRY CARCASSES IN SMALL-SCALE SLAUGHTERING FACILITIES

Birds to be slaughtered should be clean and dry; the cleaner they are the less contaminated their carcasses and meat will be (Bolder, 2007). To avoid the soiling of feathers with faeces, crates for

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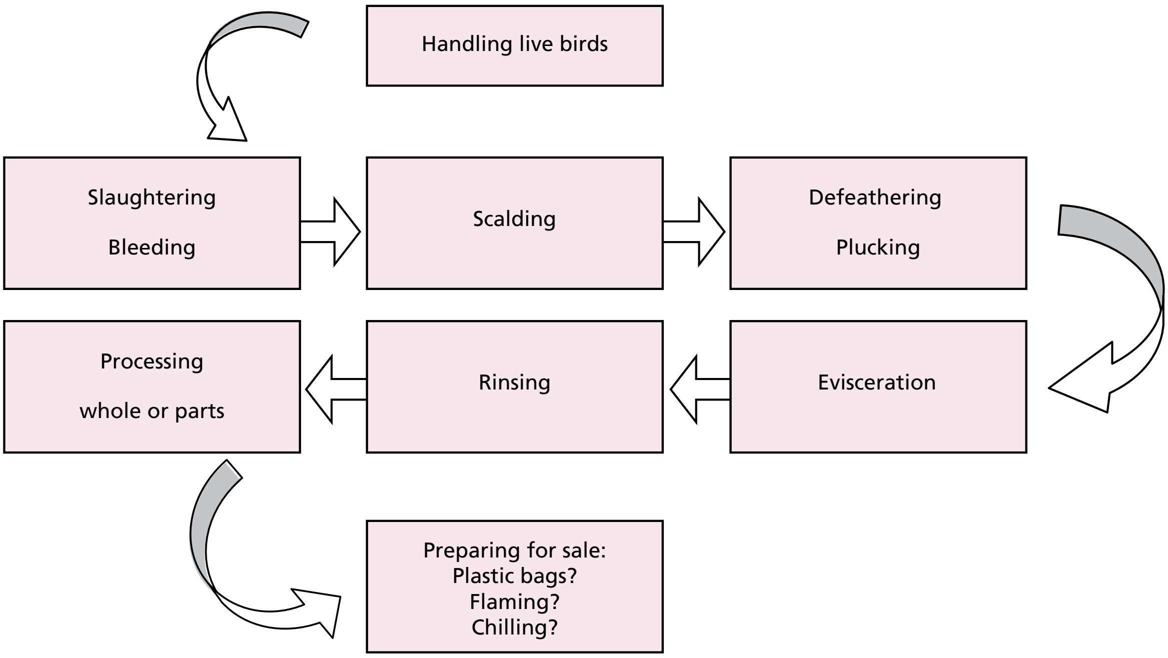
[1] With contributions from Philippe Ankers, FAO

FIGURE 1

Steps in small-scale slaughtering



transporting poultry should not be stacked on top of each other, unless there are solid partitions between them.

The people slaughtering the birds should take precautions, by washing their hands frequently and avoiding the splashing of blood on to their face and clothes.

Placing the birds into cones for slaughter prevents the spread of microorganisms, because it prevents the birds from flapping during **bleeding**. The spreading of feathers during the slaughter process is also reduced, and hygiene is improved. Blood, which can contain pathogens, is collected in the trough beneath the cone and will not be splashed.

Photo Credit: Ineke Puls

Fixation in funnels during bleeding to prevent spread of micro-organisms

Commercial poultry processing plants defeather carcasses mechanically, after the feathers have been loosened by scalding (Arnold, 2007). **Scalding** involves immersing the carcasses in hot water (for four minutes at 50 to 58°C, or by dipping several times in water at 65°C), to loosen the feathers from the skin. In small-scale operations, this scalding is often done in a cooking pan. An under-scalded carcass will be difficult to pluck, while an over-scalded one will show torn skin or cooked flesh. Harmful bacteria and viruses can survive the scalding process. In some cultures, birds are scalded in boiling water. This reduces the risk of spreading viruses, but may cook the flesh. The quality and temperature of the scalding water are critical in determining the final degree of carcass contamination. The water should be frequently replaced.

Cross-contamination among carcasses is an important problem during the **defeathering** process. Mechanical defeathering equipment work centrifugally; the carcasses are rotated and the feathers are rubbed off by rubber fingers. Carcass contamination can occur through:

- direct contact between contaminated and uncontaminated carcasses;
- compression of the carcass, resulting in expulsion of internal faeces to the carcass surface;
- the mechanical fingers;
- contaminated feathers remaining in the plucker.

At **evisceration**, the vent is opened, the internal organs are removed, and the gizzard, liver and heart may be harvested. Carcasses can be contaminated through spillage of the contents of the intestines.

Photo Credit: Centre For Livestock and Agriculture Development (Celagrid)

Mechanical fingers should be renewed regularly, as cracked and worn fingers can harbour bacteria

Photo Credit: Copyright 2008, Charlotte Observer / MCT

Hanging is hygiene!

The contamination of carcasses and meat with poultry bacteria is not the only health risk to humans; the bacteria carried by poultry workers can also be transferred to the carcasses and subsequently to consumers. *Staphylococcus aureus* is a bacterium of particular concern here. Where evisceration is done by hand, as in traditional slaughter places, there is a potentially serious risk of contamination with these bacteria. Infrequent hand-washing exacerbates the problem. The primary factor contributing to staphylococcal food poisoning outbreaks is inadequate control of temperature after slaughter, with the initial contamination often being traced to poor personal hygiene by food handlers. If slaughter is followed by storage at temperatures that permit bacterial growth and multiplication, toxins will be produced. Staphylococcal toxins are noted for their heat resistance, and typically they cannot be inactivated by the normal heat processing of food (Cohen *et al.*, 2007). This means that once the toxins are present in the uncooked meat, people will get sick even from thoroughly cooked food.

Where carcasses are **rinsed** (with a shower or spray), the water used should be of drinking quality. Washing with cold water reduces the quantity of microorganisms on the carcass in the slaughter process.

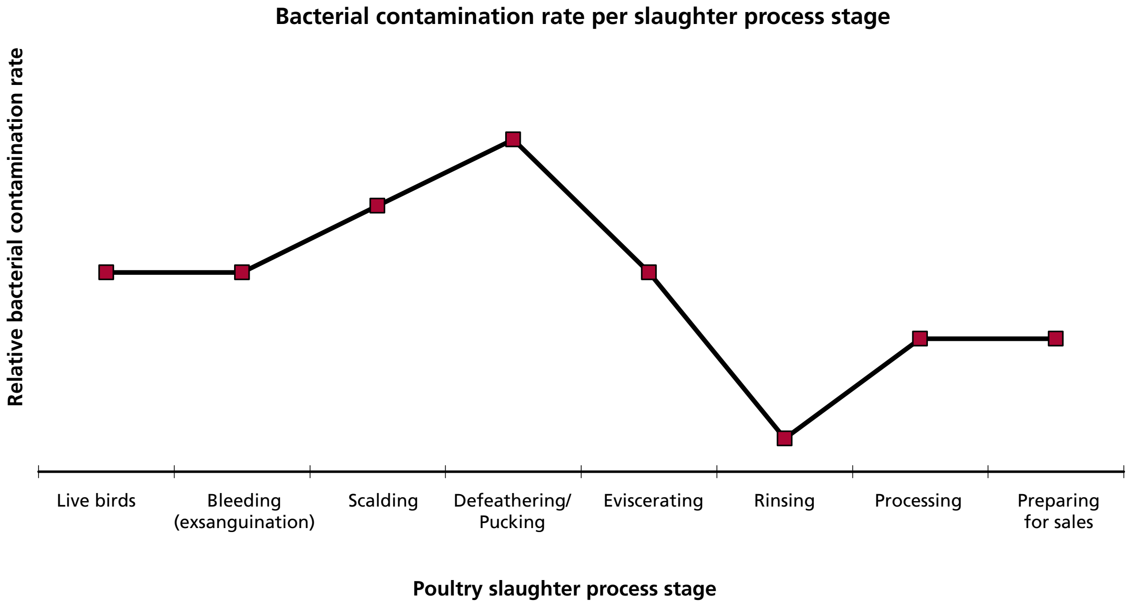
For good hygiene, and to wash away all the dirt and bacteria, etc., a regular supply of clean water is essential. Water should also always be available for personal hygiene and the cleaning of knives and other utensils. Water quantity and quality determine the level of hygiene.

Cross-contamination of carcasses can occur on working tables, sinks or draining boards during **processing**. The best way of preventing contamination of clean carcasses is to hang the birds. Abattoir workers handling the carcasses and contaminated knives can also act as vectors for the cross-contamination of carcasses.

When **preparing for sale**, bird carcasses are sometimes put into plastic bags, which prevent further carcass contamination. In

FIGURE 2

The contribution of each stage of the slaughter process to bacterial contamination



Source: Logue and Nde, 2007.

other cases, the surface of the carcass is flamed, which is a good method for reducing the number of bacteria contaminating the carcass. Quick chilling at 4 to 10° C is the best way of preventing bacterial growth.

REDUCING CONTAMINATION FROM BY-PRODUCTS AND WASTES

Feathers, especially from ducks and geese, are used for duvets and clothing. Feathers for trade are pasteurized, which kills most viruses, including H5N1 HPAI virus, and leaves the product safe (Beato, Capua and Alexander, 2009).

Poultry slaughter waste, such as carcasses, blood, feathers and offal, should be properly disposed of. It can contain viruses, bacteria and residues. In resource-poor areas, burning or burial are the most likely, practical and effective methods for disposing of waste (Nicholson, Groves and Chambers, 2005).

COMMUNICATION FOR BEHAVIOURAL CHANGE

Recently, biosecurity and good hygiene measures have been promoted more intensively in many places, in response to the risk of influenza H5N1 infection in humans. The training of trainers, workers at slaughter facilities and producers themselves helps reduce the risk of exposure.

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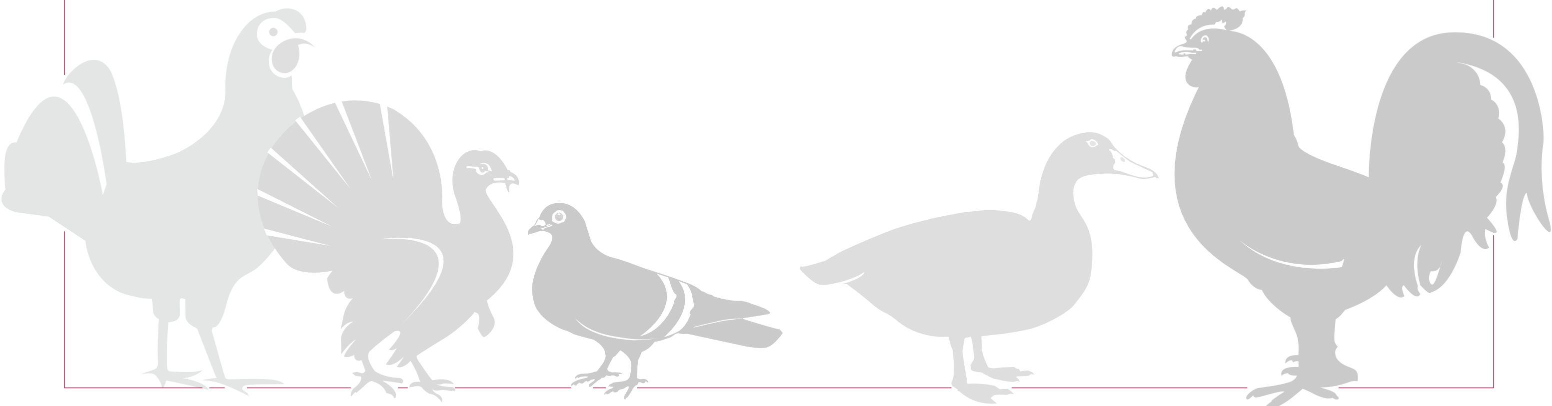
Poultry housing and management in developing countries



Poultry housing and management in developing countries

Phil Glatz, *Pig and Poultry Production Institute, SARDI, Roseworthy 5371, South Australia, Australia*
Robert Pym, *School of Veterinary Science, University of Queensland, Gatton, 4343, Queensland, Australia*

POULTRY HOUSING

Improvements to poultry housing systems in developing countries have focused on providing an environment that satisfies the birds' thermal requirements. Newly hatched birds have a poor ability to control body temperature, and require some form of supplementary heating, particularly in the first few days after hatch. Many developing countries are located in tropical areas where minimal heating is required. Indeed, the emphasis in these countries – particularly for meat chickens – is on keeping the birds cool.

Production systems

International poultry breeding and feed companies operate in many developing countries and have established large-scale commercial farms in a significant number of them. The housing and equipment used make it possible to exert considerable control over the climate provided to the birds, but such houses are expensive to build and operate, and require a large turnover of birds to make them viable. Owing to the lower construction and running costs, medium- and small-scale commercial housing is popular in developing countries. By far the most prevalent poultry farming system in many developing countries is the small-scale scavenging system, which usually involves only very basic (if any) shelter for housing birds.

Large-scale commercial farms: Commercial houses in developing countries are clear-span structures with litter on the floor for meat birds or cages for laying hens. The commercial chicken meat industry in some developing countries is vertically integrated, with single companies owning feed mills, breeder farms, hatcheries and processing plants. Arrangements typically involve agreements in which the farmer or landowner provides the housing, equipment and labour, while the company provides the chicks, feed, medication, transport and supervision.

For controlled-environment housing of layers, multi-tier cage systems are common. Most large-scale commercial farms use controlled-environment systems to provide the ideal thermal environment for the birds (Glatz and Bolla, 2004). Birds' performance in controlled-environment sheds is generally superior to that in naturally ventilated houses, as the conditions can be maintained in the birds' thermal comfort zone. Achieving the ideal environment for birds depends on appropriate management of the poultry house.

Modern houses are fully automated, with fans linked to sensors to maintain the required environment. Some commercial operators use computerized systems for the remote checking and changing of settings in houses. Forced-air furnaces and radiant heating are the main methods of providing heat to young chicks.

Medium-scale commercial: In developing countries, most medium-scale commercial layer and chicken meat houses rely on natural airflow though the shed for ventilation (Daghir, 2001). Where required, meat birds and layers are given radiant heating early in their lives, to maintain body temperature. Laying hens may be kept in commercial wire cages in open sheds, or in sheds with wire sides to exclude wild birds, scavenging poultry and predators.

Small-scale commercial (improved genotype stock and supplementary feeding): Houses of various shapes and dimensions are typically constructed using local building materials consisting of timber or mud bricks and bamboo. These small-scale commercial facilities may have several rooms or compartments where chicks are brooded, pullets are reared and layers are housed in a floor-based system or in cages. Meat birds are often kept in single-age groups of 50 to 100 chickens within the house. The house can

Sector 1 large-scale broiler operations

Photo Credit: I. Aini

Photo Credit: Olaf Thieme

Photo Credit: I. Aini

Sector 2 medium-scale layer and broiler operations

Photo Credit: Karma Nidup

Photo Credit: Karma Nidup

Sector 3 small-scale commercial houses

be used as night shelter for birds that forage under free-range conditions or that are confined to an outdoor pen during the day.

Small-scale semi-scavenging system using indigenous birds: When provided, shelters are made from various materials, including wood and leaf material from local trees or shrubs. Birds in the household flock are typically housed overnight in the shelter, and are let out in the morning to forage during the day (Ahlers *et al.*, 2009). If no special structure is provided, the birds sometimes shelter overnight under the farmer's house or even inside the house with the family. Where provided, the usually rudimentary house comprises posts, a thatch or scrap iron roof, and thatch or scrap wire netting walls. Feeders, perches, drinkers and nest boxes made from local materials are sometimes provided, and special shelters of a wide variety of designs and constructions are sometimes used to house broody hens with their chicks.

Photo Credit: Viengsavanh Phimphachanhvongsod

Photo Credit: Viengsavanh Phimphachanhvongsod

Sector 4 small-scale, semi-scavenging poultry production

Ventilation management

All poultry houses need some form of ventilation to ensure an adequate supply of oxygen, while removing carbon dioxide, other waste gases and dust. In commercial operations, minimum ventilation is often practised in colder climates, but not generally in tropical ones (Glatz and Bolla, 2004).

In large-scale automated operations, correct air distribution can be achieved using a negative pressure ventilation system. When chicks are very young, or in colder climates, the air from the inlets should be directed towards the roof, to mix with the warm air there and circulate throughout the shed. With older birds and in warmer temperatures, the incoming air is directed down towards the birds, and helps to keep them cool. Evaporative cooling pads can be placed in the air inlets to keep birds cool in hot weather. Tunnel ventilation is the most effective ventilation system for large houses in hot weather.

Tunnel ventilation: These systems are popular in hot climates. Exhaust fans are placed at one end of the house or in the middle of the shed, and air is drawn through the length of the house, removing heat, moisture and dust. Evaporative cooling pads are located at the air inlets. The energy released during evaporation reduces the air temperature, and the resulting airflow creates a cooling effect, which can reduce the shed temperature by 10 °C or more, depending on humidity. Maximum evaporation is achieved when water pumps are set to provide enough pad moisture to ensure optimum water evaporation. If too much water is added to the pads, it is likely to lead to higher relative humidity and temperatures in the shed.

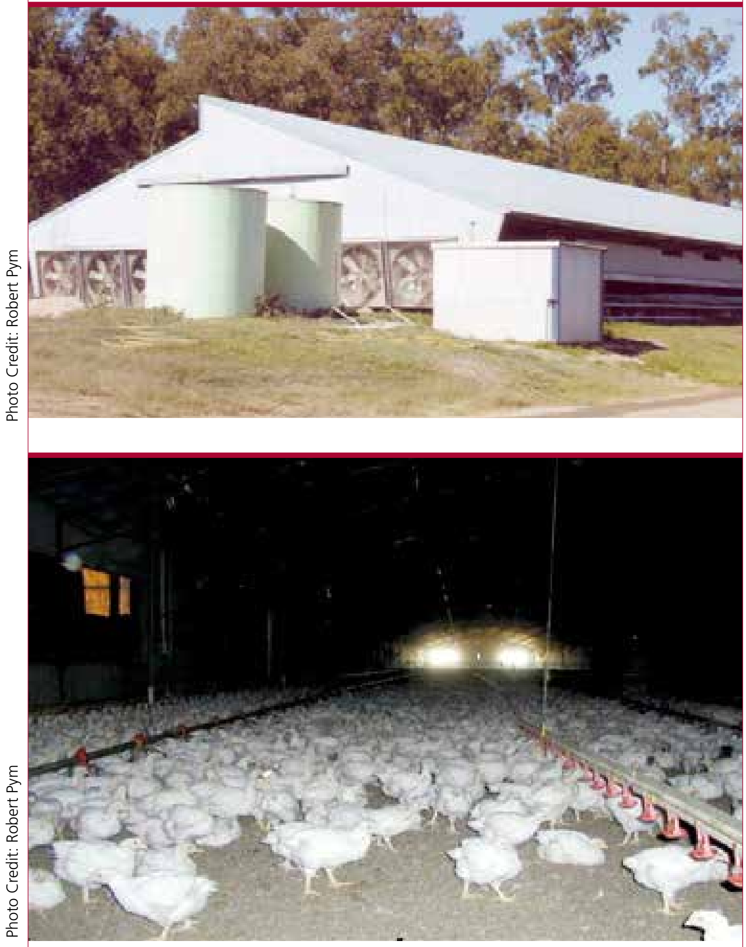


Photo Credit: Robert Pym

Photo Credit: Robert Pym

Tunnel-ventilated broiler house: exterior and interior views

Fogging systems: Fogging systems are sometimes used to reduce the shed temperature. Fogging works best in dry climates, and usually involves several rows of high-pressure nozzles that release a fine mist throughout the house. The cooling effect is significantly increased by airflow from the use of fans within the shed.

Natural ventilation is common in medium- and small-scale operations and in areas where the climatic conditions are similar to the temperatures required by birds. Ventilation is usually provided by prevailing breezes. Natural ventilation works best in poultry sheds where the long axis runs east to west, to avoid heating of the sidewalls by the sun during the morning and afternoon.

POULTRY MANAGEMENT

The aim of management is to provide the conditions that ensure optimum performance of the birds (Bell and Weaver, 2001). Given reasonable conditions, broody hens are very successful at hatching their chicks, but good hatchability using artificial incubation (both large and small) relies on careful management of temperature, humidity, ventilation, position and egg turning. During incubation, the egg loses water vapour through its shell. The rate of water loss depends on both the shell structure and the humidity of the air surrounding the egg. The quality of the hatch also depends on the age and health of the breeder flock, and on the evenness and cleanliness of the eggs set.

Factors involved in poultry management

Poultry management involves monitoring poultry health; ensuring that the poultry house is maintained with appropriate brooding, rearing, growing and laying conditions; and ensuring that recommended vaccinations are given and appropriate feeding programmes are used. In developing countries, it is often difficult to achieve optimum performance from birds, owing to less-than-optimal housing conditions and lack of quality feed, vaccines and trained staff.

Breed effects

Owing to their superior production, commercial hybrids of high genetic merit are often used in developing countries, but are not well-suited to tropical environments (see website on Poultry genetics and breeding in developing countries). These birds are sensitive to changes in the diet and to high ambient temperature, and require skilled stockpersons to manage them. Indigenous poultry can cope better with the harsh conditions often prevailing in developing countries, and good management will improve their performance. This can be achieved by using good housing, protecting the birds from predators, and providing them with the environmental conditions that allow them to achieve maximum profitability.

Temperature effects

Farmers need to compensate for undesirable climatic conditions by manipulating control systems or modifying the house to ensure that the welfare and environmental needs of the birds are satisfied. Environmental extremes (heat and cold stress, excessive or inadequate ventilation, poor air quality) can be managed if the design of the poultry house is appropriate for the conditions. Birds require adequate space, sufficient feed to meet their nutritional requirements, and an adequate supply of good-quality water. Use of a stringent quarantine programme to prevent disease is an essential element of good management, and farmers must be able to recognize disease and treat it as soon as possible. A suitable vaccination and medication programme is essential in commercial operations.

Effects of nutrition

Managers need to ensure that the diets provided to birds in commercial operations meet the nutrient requirements of each age group and strain of chickens (see website on Poultry feed availability and nutrition in developing countries). Smallholder systems in developing countries typically place less emphasis on achieving maximum production, and more on maximizing profitability by using diets comprised mainly of local feedstuff ingredients, rather than imported feeds. Key management practices by farmers who mix their own feed include ensuring that micro-ingredients are kept cool, mouldy ingredients are not used, and storage facilities are weather- and rodent-proof.

Importance of good hygiene

An essential management task is to maintain clean sheds, surroundings and equipment. A clean shed improves health and limits parasites, dust and microbial contamination, while clean shed surroundings reduce vermin and fly loads. This is important not only for litter and manure management but also for biosecurity. Removal of residual feed from feeders is an important practice critical to the health of the flock. Another important management task is to sanitize sheds to minimize the risk of disease to incoming flocks of birds. Maintaining high flock health status is essential, and routine vaccination programmes for a number of diseases are typically in place, particularly in larger-scale operations. Some vaccinations are carried out at the hatchery, but it is essential that a proper vaccination schedule be established and that vaccination protocols be complied with.

Litter materials and management

Broiler litter is the material used as bedding in poultry houses to absorb faecal waste from birds and to make the floor of the house easy to manage. Common litter materials are wood shavings, chopped straw, sawdust, shredded paper and rice hulls, and a wide range of other materials are used in different regions around the world. Litter should be light, friable, non-compressible, absorbent, quick to dry, of low thermal conductivity and – very important – cheap. After use, the litter comprises poultry manure, the original litter material, feathers and spilled feed. The litter quality in a shed is determined by the type of diet, the temperature and the humidity. The recommended depth for litter is between 10 and 20 cm. Sawdust can result in high dust levels and respiratory problems. Dust particles in the litter capable of causing health problems in the birds are derived from dried faeces, feathers, skin and litter; their adverse effects arise because they carry or incorporate bacteria, fungi and gases.

Management of lighting

Poultry have seasonal and daily biological rhythms, both of which are mediated by light, particularly day length. For day length to exert its controlling effect, there needs to be a dark phase (night) when light levels should be less than 0.5 lux. Day length and light intensity during the breeder bird's life have an important role in development of the reproductive system. The difference in day lengths and light intensities between the rearing and the laying phases is the principal factor responsible for controlling and stimulating ovarian and testicular development (Lewis and Morris, 2006). The response to increases in day length and lighting intensity depends on the body weight profile during rearing, which in turn depend on the nutritional regime. The effects of light are predominantly on the rate of sexual maturation and egg production.

The two types of artificial lighting commonly provided are incandescent and fluorescent. Incandescent globes are cheaper to install, but have lower light efficiency and a shorter life. Fluorescent lights are three to four times as efficient and last about ten times as long, but have variable performance in cold weather. The colour of the light rays has an effect on chickens' productivity. For example, green and blue lights improve growth, and lower age at sexual maturity, while red, orange and yellow lights increase age at sexual maturity, and red and orange lights stimulate egg production. Birds are calmer in blue light, so blue lights are recommended for use during depopulation in commercial operations.

Lighting programmes for broilers: Lighting programmes for commercial broiler operations vary widely from company to company, and depend on the strain of bird used, the housing type (naturally ventilated versus controlled-environment), the geographical location and the season. Where light can be excluded from sheds, birds are typically reared under low-intensity (5 to 10 lux) lighting, to keep them calm and to prevent feather pecking. During early brooding, 25 lux is used to stimulate feeding.

Lighting programmes for layers and breeders: Light is critical for the onset and maintenance of egg production. Increasing day length (from winter to summer) during the rearing period stimulates the onset of sexual maturity, whereas shortening day length (from summer to winter) has the opposite effect. Early onset of lay may not be beneficial as it may predispose to reproductive problems. Where artificial lighting is possible, a constant day length (of between 12 to 16 hours per day) during the rearing period has been shown to result in a delayed onset of lay, and is the preferred rearing treatment. Shortening day length or too little light will discourage egg production, and must be avoided once the birds are in lay.

Stockpersonship

Farmers and their staff play a critical role in looking after the birds and maximizing productivity. They need to empathize with and care about their birds, and to avoid exposing them to adverse situations that may cause stress (see website on Poultry welfare in developing countries). The people responsible for the care of poultry should be well trained, experienced and dedicated. The first task for poultry staff is to learn how to carry out routine checks on the birds, so they can identify what is normal in the flock and what the signs of trouble are. Good stock attendants minimize the risks to their animals' health and welfare. By doing this, they allow production to reach its potential, while treating the animals with care (Barnett and Glatz, 2004). This is sometimes called "stockpersonship". Staff should be able to identify quickly any changes in the flock and in the birds' environment, and any physical, chemical or microbiological threats, such as damaged equipment, mouldy feed or infectious disease, and should prevent problems from escalating. The more sophisticated the poultry farming system, the greater the management skills required.

Records

Record keeping and meeting production targets are good management practices that allow the identification and solution of problems. When a problem is identified, the next step is to attempt to fix it. Identifying the cause of and fixing a problem is an important part of the farmer's knowledge base, and is likely to assist in preventing a recurrence of the problem (Barnett *et al.,* 2001). Records kept over time can help identify some of the possible causes of problems. One of the most useful record-keeping documents is a diary, which can be used in combination with record-keeping sheets to record major activities, problems identified, equipment repairs, deviations from equipment settings, and any staff issues.

Records of production, growth, feed, egg weights, mortalities, treatments given, and response to treatments should be maintained to assist investigations of sub-optimal performance. In all production systems, signs of ill health can be detected when poultry reduce their food and water intake; reduce production or growth; undergo a change in appearance, behaviour or activity level; or have abnormal feather condition or droppings.

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Incubation and hatching

Phil Glatz*, Pig and Poultry Production Institute, SARDI, Roseworthy 5371, South Australia, Australia*

On village farms, fertile eggs are hatched mainly using broody hens. On semi-commercial and commercial farms, they are hatched artificially in incubators.

Hatching fertile eggs using broody hens

One of the important characteristics of village hens is their capacity for broodiness. The large majority of improved-breed birds have lost this capacity. When broody birds are approached, they make a typical brooding noise and fluff up their feathers. Broody hens prefer to sit on eggs in a dark environment that is protected from predators, and they need a supply of feed and water. When one or more cockerels are present in the flock and have been observed mating regularly with females for a week or more, the eggs will normally be fertile (CTA, 2007).

Quality of fertile eggs

Hatching eggs (stored at 16 to 17 ^{0}C) need to have good shell quality. Storing eggs at higher temperatures promotes the development of the embryo. In many developing countries it is difficult for village farmers or breeding centres to store eggs under ideal conditions. Under high temperature conditions, the eggs are likely to "sweat", allowing bacteria to penetrate the shell. Relative humidity should be maintained at approximately 75 percent in the fertile egg holding room. Higher humidity encourages mould growth on eggs.

Pre-warming of fertile eggs

Eggs need to be warmed to room temperature for approximately eight to 12 hours before they are set in the incubator. The purpose of pre-warming is to minimize temperature shock to the embryo and condensation on the shell. It also reduces the variation in hatch time. Good air circulation is essential for an even pre-warming of eggs.

The incubator room

Optimum results can be expected if the temperature in the incubator room is maintained at about 25 ^{0}C. However, the tropical climate in many developing countries makes it difficult to maintain good incubator room conditions.

Incubators

In small hatcheries in developing countries, incubators are often small, still-air machines with a capacity of 12 to 240 eggs. The relative humidity must be 55 to 60 percent at set, and increased to 75 percent after day 18. In small incubators, this is normally achieved by placing an extra container of water in the incubator. The eggs are set in a horizontal position and are turned manually. The source of heat is usually a thermostatically controlled heating element or light bulb or kerosene lamp. Humidity is supplied by water in a container either above or below the eggs, and ventilation is controlled by small air vents. Circulating-air incubators have an electrically driven fan to maintain constant temperature and ventilation of the eggs.

In large-scale operations in developing countries, incubator setting capacity ranges from approximately 10 000 to 100 000 eggs. The equipment used to incubate and hatch chicks is all precisely controlled (Cobb-Vantress, 2008). Optimum temperatures for setters are 37.1 to 38.6 °C, at a relative humidity of 60 to 70 percent. The hatching eggs are set vertically, with the blunt end uppermost in the setter, and are turned mechanically through 90° every hour

Photo Credit: Olaf Thieme

Hatching by a broody hen

Photo Credit: Olaf Thieme

Kerosene operated incubator in small hatchery

Photo Credit: Robert Pym

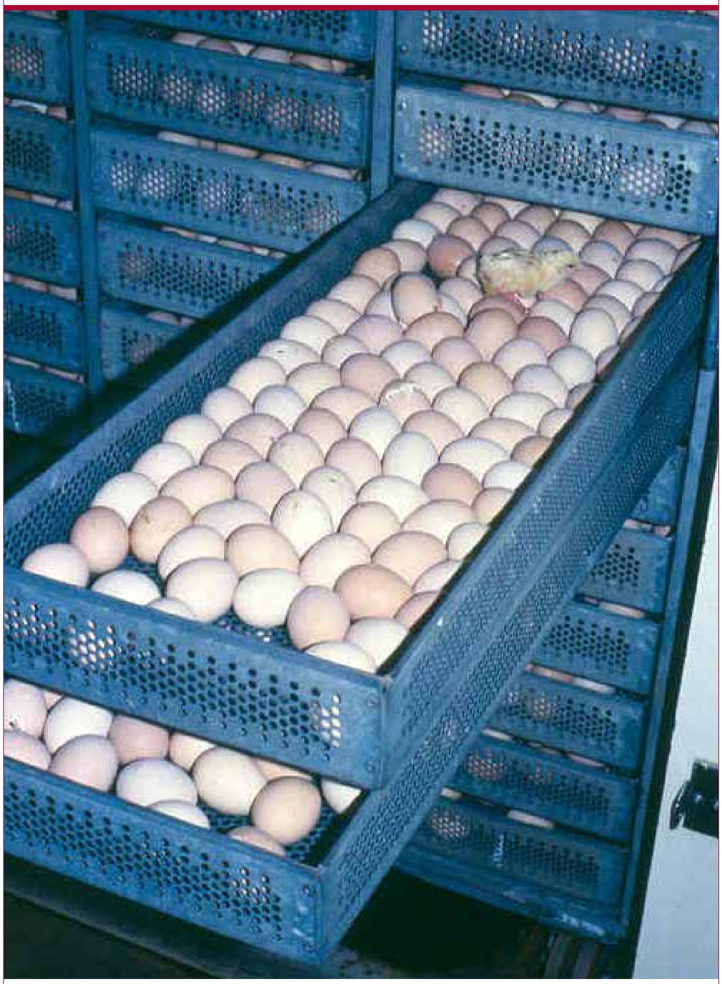

Photo Credit: Robert Pym

Large-scale commercial incubator and hatcher

until about three days prior to hatching. The eggs are then transferred to a hatcher, where they are placed on hatching trays on their sides, with the long axis horizontal, to allow the chick to move freely out of the shell at hatching. Hatcher temperatures are usually slightly lower than those in the setter, to reduce the risk of overheating, and are typically 37 to 38 °C, while relative humidity is usually raised to about 75 to 80 percent. Hatchability should be in the range of 80 to 90 percent for imported hybrid strains, but varies with the breed and the age of the breeder flock.

Egg candling

Candling of chicken eggs on the seventh and eighteenth days of incubation is recommended for small poultry producers and commercial farms. Egg candling (using a torch or bright light in a dark area) detects cracked and infertile eggs and those containing dead embryos or bacterial or fungal rots; these eggs can then be removed from the incubator. Cracked and rotten eggs must not be allowed to remain in the incubator as they can explode and result in infection of the hatching chicks.

Fumigation of incubators

The effectiveness of formaldehyde gas in killing bacterial organisms is based on the concentration of the gas, the exposure time, the temperature and the humidity of the incubator. The chemicals potassium permanganate and formalin are mixed together to release formaldehyde gas. This procedure has proved to be the most effective method of destroying bacterial organisms in the hatchery.

HATCHED CHICKS

The chicks hatch after 21 days of brooding or incubation. If the eggs have been hatched by a hen, she will immediately take care of the chicks, but will typically remain on the nest until the majority of the eggs have hatched. If the chicks have been hatched in an incubator, they are ready to be taken out of the hatcher when most of them are dry and fluffed up. Chicks will easily dehydrate if left in the hatcher for too long. They have yolk reserves for about three days, but survival rates are increased if they are provided with food and water within 24 hours of hatching. Chicks are normally removed from the hatchers within 24 hours of the first chick hatching. The chicks should be held in an environment that prevents overheating or chilling. Temperatures should be in the range of 30 to 32 °C, and relative humidity in the range of 70 to 75 percent. Adequate ventilation is vital at all times, to provide the chicks with a constant and uniform supply of fresh air.

Vent and feather sexing

Sexing of day-old chickens is not normally practised on village farms, but is an essential procedure in commercial operations with modern hybrids, particularly for layers, where the male chick has no commercial value. Broilers are also often sexed, but the requirement here is less important. There are two fundamentally different approaches to sexing: one identifies the sex of the day-old chick by sex organ-related differences; and the other employs sex-linked genes (Barnett *et al.*, 2001). In the first approach, sexing can be done in any population using one of two methods: i) vent sexing, which relies on visual identification of the sex organs using an endoscope inserted into the chick's vent; and ii) cloa-


Photo Credit: Robert Pym

Day-old chicks in 100-bird chick boxes following hatch

cal sexing, where the chick's cloaca is everted and the vestigial copulatory organ can be seen in male chicks. Both of these procedures require extensive training. The second approach involves fixing appropriate sex-linked feathering rate or colour genes in the parental lines (see website on Poultry genetics and breeding in developing countries). In the progeny from such matings, male chicks are either slow-feathering or white, and hatchery staff can readily distinguish them at hatch from their rapid-feathering or coloured-feathered female counterparts.

Culling chicks in the hatchery

Culling is conducted to reduce the potential for transferring disease within flocks, to provide a uniform hatch of chicks for production, and to reduce pain and suffering of sick and deformed chicks.

There are three methods for culling surplus or sick chicks (Barnett *et al.,* 2001):

- Cervical dislocation: The neck of the day-old chick is held against a firm surface (e.g., the edge of a tabletop) and gentle pressure from both thumbs is applied to dislocate it. This method can be used on small farms.
- Gas stunning with carbon dioxide: The chicks are held in a container covered with a lid or plastic. They are initially stunned and then killed with longer exposure. A concentration of 55 percent carbon dioxide in air is required to kill the chicks with two minutes exposure time.
- High-speed macerators: Some larger hatcheries use these to kill unwanted chicks and any live chicks in eggs that have failed to hatch.

Removal of claws and spurs

In commercial operations, it is routine for male breeding birds to have the terminal segment of the inner toe removed, to prevent damage to female birds while mating. This is routinely done at the hatchery, although about 10 percent of chicks may have their claws removed on-farm. It is best to use a beak trimming machine to cut and cauterize the wound, although scissors can also be used. Males may also have their spurs removed, again preferably using a beak trimmer to cut and cauterize the wound (Barnett *et al.,* 2001). Sharp scissors can be used, but the wound is not cauterized, and there is a risk of excessive bleeding. This procedure is necessary to prevent damage to birds when fighting. In village farms, the sharp points of the claws and spurs can be blunted with abrasive material.

Bird identification

A small percentage of breeding birds require individual identification. Methods used for small numbers of birds include either cutting the skin between the toes (the webbing) with scissors or a scalpel blade, or trimming the digits with sharp scissors or a beak trimming blade (Barnett *et al.,* 2001). For larger numbers of birds number-embossed wing bands or leg bands are necessary. Wing bands are attached to the bird by passing the pin or sharp point through the web of the wing. Leg bands are fastened around the metatarsus above the foot.

Wing-bands can be applied at hatch, but leg-bands can not be applied before about 12 weeks of age, due to rapid increase in the diameter of the leg up until about this age.

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Brooding and management of young chicks

***Phil Glatz**, Pig and Poultry Production Institute, SARDI, Roseworthy 5371, South Australia, Australia*

Hatched chicks should be active, uniform in size and healthy. Although newly hatched chicks can survive on their own body reserves for up to 72 hours, depending on environmental conditions, their survival is increased if they are provided with food and water within 24 hours of hatching. The sooner they are provided with these and a warm area, the higher the rate of survival. Chicks must not be chilled or overheated at any time.

BROODING SYSTEMS

Broody hens

Under natural conditions, the mother hen keeps the chicks warm by allowing them to nestle under her feathers. The chicks follow the broody hen around and learn to forage and drink by watching her behaviour. In small village poultry settings, hens can care for up to 15 chicks. Ideally, chicks should be provided with a commercial ration (Ahlers *et al.*, 2009) or other feed for at least the first two weeks, to improve the survival rate.

Spot brooding

For small flocks of up to 20 chicks, a small enclosure in the poultry house or a confined area can be set up. This can be made from cardboard or timber, with a heat lamp suspended over the enclosure to keep the chicks warm. When the chicks are provided with an ideal temperature, they spread uniformly over the enclosure. When chicks feel cold, they crowd under the heat source. If the pen is too warm, the chicks move away from the heat and pant with their wings spread out (Bell and Weaver, 2001).

For larger flocks of up to 400 chicks, circular enclosures are set up in the poultry house to retain them. These areas are usually made from Masonite or sheet metal, with a gas brooder suspended over them to provide the required temperature (about 35 °C immediately under the brooder). There should be sufficient space for chicks to move away from the heat source. Temperatures in the outer part of the enclosure may be as low as 20 °C.

Commercial layers are often raised in growing cages (of up to 20 chicks/cage) with warm-room brooding, or with a heat source over each cage in tropical climates. As the birds age, the stocking density is reduced by moving chicks to other growing cages.

Whole-house brooding

In large commercial operations, the whole shed is maintained at a temperature of 30 to 32 °C both day and night, using forced-air heaters. This can be achieved only if the shed is completely sealed. As most developing countries are located in the tropics, there is usually no need for whole-house brooding. When this system is used, the house temperature is lowered by about 2 to 3 °C per week until it reaches ambient temperature, provided this is not below 18 °C.

Chick feeders

At one day old, feed for the chicks can be scattered on paper. After three to four days, the paper can be removed, and chicks provided with feed in shallow feeders on the floor or cages.

Chick drinkers

For village chicks, drinkers can comprise bamboo sections or water bottles. These should be cleaned and refilled daily. Feed and

Photo Credit: Robert Pym

Older style brooding cages for layer chicks: hot water pipes run along and above the brooder section at the back of the cages; an oil- or gas-fired heater heats the water

Photo Credit: Robert Pym

Oil or gas-fired hot air brooder units on side of shed for whole-house brooding: the entire brooding area is heated to the required temperature

Photo Credit: Robert Pym

Conveyor and pan automated feeding system for young chicks: for the first five days post-hatch every third pan in the line is replaced with scratch trays

water should be within 1.5 m of all chicks. In large flocks, automatic drinkers are typically used. These can be nipple, cup or bell waterers.

Daily management of chicks

Chicks should be checked four times a day, taking note of any abnormal behaviour and ensuring that they are healthy and not heat- or cold-stressed (Barnett and Glatz, 2004). They should be observed to see if they are able to eat and drink successfully from the equipment provided. Any dead chicks should be removed, and litter should be dry.

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Housing and management of breeders

Phil Glatz, *Pig and Poultry Production Institute, SARDI, Roseworthy 5371, South Australia, Australia*

HOUSING OF BREEDERS IN DEVELOPING COUNTRIES

In village settings, some farmers use bush materials to construct houses for their breeder chickens, which provides some protection. Typically, a village flock comprises ten to 12 layers with one or two cockerels. Natural incubation by broody hens is common, and egg fertility ranges from good to poor, depending on several factors. The decision to construct a house for chickens is often determined by the individual farmer's access to materials, the availability of space within the village, and other social and economic factors. However, the houses built are basically for night shelter, and the breeding birds are left to scavenge for feed during the day, thus they remain prone to predators even though shelters are provided.

In commercial and semi-commercial settings in developing countries, breeders are normally housed in naturally ventilated houses, with some additional lighting provided if electricity is available. The house is usually fitted with nest boxes, feeders and drinkers. Some large-scale operations use automatic feeding and egg collection systems.

BREEDERS IN DEVELOPING COUNTRIES

A number of government, non-governmental and training organizations have developed poultry breeding programmes for producing local chickens in developing countries. Some centres have imported improved commercial strains for crossing with the local chickens to improve the meat and egg production of smallholder poultry flocks. The breeding centres often distribute chicks to farmers for use in their village farm operations. Larger commercial integrated poultry franchises in developing countries normally import fertile eggs from commercial layer or broiler breeder flocks. These eggs are set in large hatcheries, and hatched chicks are either sold in small lots to village farmers or used in commercial or semi-commercial operations to produce chicken meat and eggs for consumers in towns and cities.

The poultry breeding facilities established in developing countries are normally small-scale. Ideally, the breeding flock should comprise females with good egg production, which are mated with active cockerels. A major issue is maintaining a supply of fertile eggs. Young breeder flocks produce fewer fertile eggs than those at peak of lay, and fertility also tends to be lower in eggs produced by older breeders. Hatchability and the uniformity of hatched chicks depend on management of the eggs produced by the breeders. In larger-scale operations, eggs should be collected at least four times a day, handled carefully to prevent breakages, and stored for no longer than seven days in a cool room at 15.5 to 17 °C and relative humidity of 75 percent. Eggs on the floor or that are dirty should not be set. In small-scale village operations, farmers can clean dirty eggs with abrasive paper and make use of all the eggs that are available.

BREEDER CHICK MANAGEMENT

Chicks that are reared for use in a breeding programme should be kept separate from other birds in other age groups. Cockerels should also be grown separately from females, preferably until five months of age. Generally, however, this approach is not possible in village operations. Most chick rearing in hot-climate developing countries is carried out in naturally ventilated houses. In commercial operations, chicks scratch in the litter, creating uneven litter levels, particularly around feeders and drinkers. Small

Photo Credit: Viengsavanh Phimphachanhvongsod

Small-scale breeding programme with indigenous breeds

Photo Credit: Robert Pym

Broiler breeder hens and cocks in a deep-litter naturally ventilated house birds will not be able to reach the feeders or drinkers if the litter levels are not kept even. In large commercial operations in colder climates, the building should be pre-heated so the floor is warm and the air temperature close to 32 °C when the chicks are placed. If provided, lighting should be continuous for the first 48 hours after the chicks arrive.

Beak trimming is practised where required to prevent injurious pecking in the flock. Males often need re-trimming before they enter the breeding programme, to reduce the risk of pecking damage to the females during mating.

GROWTH AND PRODUCTION

During the rearing and growing period for breeder stock the major objective is to control body weight, particularly to ensure that all the birds reach target weight-for-age uniformly. Body weight targets are achieved by controlling feed allowances. Feed amounts during rearing are based on body weight and maintenance; during lay, egg production and egg weight are also important (Cobb-Vantress, 2008a).

In meat and layer type birds, body weight uniformity is critical during the first six weeks of the breeders' growth. Weekly body weight increase is a good indicator of how successful the brooding has been. High-quality feed of appropriate particle size must be provided to obtain adequate feed intake in the first week. Crop size is a good guide to how well the chicks are consuming feed and water. In developing countries, it is often difficult for breeder farms to meet the body weight standards set for developed countries, owing to poor feed quality and the typically hot environment.

During the period from six to 16 weeks, meat and layer breeders are usually put on a controlled feeding regime to keep their body weight on target. When the birds reach 16 weeks, they are stimulated by providing up to an hour of additional artificial light per day, to promote sexual development. Particularly in layer strain breeder flocks, it is essential that the female parent achieves sufficient body weight between 16 and 20 weeks of age, to maximize peak egg production and achieve consistent egg production throughout lay. Breeder flock egg production can be optimized by appropriate feeding programmes that ensure that the pullets have uniform body weight. It is also important to keep the breeding flock body weight in check after maturity, by handling and weighing birds often and adjusting the feeding levels as required.

Layer breeding stock should be fed daily from hatch to end of lay, whereas for broiler breeders during the rearing phase, skip-a-day feeding is often used because of the relatively severe restriction that is needed to achieve the desired body weight in these much heavier birds. Uniformity and bird welfare suffer if daily feeding is used, as the more timid birds miss out on their daily allowance. On the alternate days, scratch grain is often provided to reduce hunger. During the laying period, from about 21 weeks of age, broiler breeders are typically fed a restricted amount daily. The restriction at this time is considerably less severe than it is during the rearing period. Separate-sex feeding is normally practised during the laying period, with males having no access to females' feed, and vice versa. This has more to do with diet composition than quantity, as males have a far lower calcium requirement than females.

LIGHTING PROGRAMME MANAGEMENT

The onset of lay in layer and broiler breeder hens is critically linked to change in day length: increasing day length stimulates the onset of sexual maturity, while decreasing it has the opposite effect. In developing tropical countries, natural day-light rearing of breeding stock is generally used, and works well, because the variation in natural day length is small. During the rearing period, birds can remain in natural light in all seasons until artificial light stimulus is given, normally at 20 or 21 weeks of age in meat breeders and from 18 weeks in layer breeders. When extending the day length, artificial light is provided at both the beginning and the end of the natural day-light period (Lewis and Morris, 2006).

WATER MANAGEMENT

Breeding birds in village systems are normally provided with water in open containers. Most commercial operations provide one bell drinker per 80 birds, while nipple drinkers, which are a more hygienic water delivery system, are provided for eight to ten birds per nipple. Chickens normally drink between 1.6 and 2.0 times their daily feed intake at 21 °C, in both *ad libitum* and control fed flocks. At ambient temperatures higher than 30 °C, water consumption increases to more than twice the feed intake. High water consumption may indicate errors in feed formulation or leaking drinker systems.

RELOCATING BIRDS

In village farming systems, breeder birds are often sold and transferred to other village farms. In semi-commercial and commercial operations, the age for transferring stock to other farms is determined mainly by the facilities available, the birds' body weight and the lighting programme. Transfer can be very stressful for the birds, and every effort should be made to ensure that it is carried out smoothly. It is best to transfer males a week earlier than females, so they can adjust to their feeding system. The ratio of males to females is usually kept at about 1:10, and males should be healthy with no obvious skeletal defects.

PRODUCTION PERIOD

In most developing countries, manual nesting systems that allow about four birds per nest are used. Young breeder males are often added to an older flock to overcome the decline in fertility that usually occurs after peak egg production. Older males usually undergo a decline in mating activity and a reduction in sperm quality.

EGG WEIGHTS

There are considerable advantages in weighing a sample of eggs to establish the trend in egg weight. Analysis of this trend provides a useful guide to breeder flock performance, and gives early indication of problems. An egg weight that is too low could be the result of insufficient feed or water intake, high shed temperatures or disease. If egg weight is too high, birds may be overweight or overfed.

EGG HANDLING

On larger breeder farms, eggs are collected two to three times a day and kept in a cool place for three to four days before setting. If held for longer than seven days, they must be stored at 16 to 17 °C.

Maximum hatchability and chick quality can only be achieved when the egg is held under optimum conditions between laying and setting in the incubator (Cobb-Vantress, 2008b). It is normal practice to sanitize hatching eggs prior to setting. Methods commonly used are formaldehyde fumigation, dipping in ammonium solutions, ultraviolet light and ozone. Eggs should be allowed to cool gradually before being placed in the cool room at a relative humidity of 75 percent.

In larger commercial operations, vehicles that maintain a temperature of 16 to 18 °C are used to transport eggs from the breeder farm to the hatchery. Fertile eggs are also maintained under cool conditions when they are transported by air. During loading, care must be taken to avoid egg breakages when carrying and stacking the egg fillers. Particular care must be taken when transporting eggs on rough roads, which are common in developing countries.

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Housing and management of broilers

Phil Glatz*, Pig and Poultry Production Institute, SARDI, Roseworthy 5371, South Australia, Australia*

MANAGING THE ENVIRONMENT

The most important aspect of broiler chick management is producing an environment without temperature fluctuations. This is difficult to achieve in village operations, but commercial systems can do so in a number of ways, through whole-house brooding, or partial house brooding to conserve heat and reduce energy costs (Cobb-Vantress, 2008). Correct temperatures are more easily maintained in a small area. Ventilation also needs to be considered, as it distributes heat to the birds and helps maintain good air quality in the brooding area. Chicks are more susceptible to poor air quality than older birds are. High ammonia levels have been shown to reduce the body weight gains of seven-day chicks by 20 percent.

In semi-commercial and large-scale operations, lights are needed along the brooding area above the heat source in the house, to attract chicks to the feed and water. These lights should be used during the first five days after the chicks arrive, after which background lights should be gradually increased, to reach normal lighting by the tenth day.

A well-insulated roof reduces solar heat penetration into the house on warm days, thus decreasing the heat load on the birds. In village settings, many farmers use discarded iron for roofing, but local leaf material made into thatch is preferable (especially in tropical countries), as it insulates the building from extreme heat.

In cold weather, a well-insulated roof reduces heat loss and the energy consumption needed to maintain the correct environment for broiler chicks during the brooding phase. In poorly insulated buildings, an area can be set up inside the shed where temperature fluctuations can be minimized by using curtains and a false ceiling running from eave to eave, to reduce heat loss and make temperature control easier.

STOCKING DENSITY

It is essential that meat birds have adequate room, whether they are housed in small groups on village farms or in larger semi-commercial or commercial sheds. Lack of space can lead to leg problems, injuries and increased mortality (Sainsbury, 1988). As they approach market weight, an approximate maximum stocking density for fully confined birds on deep litter is 30 kg of bird per square metre of floor area.

DRINKER MANAGEMENT

Providing clean, cool water is critical in broiler production. Without adequate water intake, feed consumption will decline and bird growth will be depressed. There are many types of drinkers; in high temperature conditions, drinkers that allow water circulation and cooling are best. In small-scale operations, it is important to keep drinkers topped up, to clean and refill them daily, and to locate them in a cool part of the pen or cage, away from any heat source or the sun's rays.

FEEDING MANAGEMENT

If feeder space is insufficient, growth rates will be reduced and uniformity will be compromised. Feed distribution and the proximity of the feeder to the birds are essential for achieving optimum feed consumption rates. In tropical developing countries, the main factor reducing feed consumption is high temperatures. Feed should be withheld at the hottest time of the day, to prevent heat stress and the resultant mortality. Pan feeders are better than

Large-scale naturally ventilated broiler house

Photo Credit: Robert Pym

Sector 3 small-scale broiler house (Bhutan)

Photo Credit: Karma Nidup

trough feeders, as they allow unrestricted bird movement around the feeder and there is lower incidence of feed spillage and improved feed conversion.

In most commercial operations, automated pan or trough and chain feeders are used, providing 2.5 cm of feeder space per bird. To reduce feed spillage, the lip of the feeder should be level with the bird's back. An issue in developing countries is ensuring continuity of feed supply. This can be achieved by having a rodent-proof storage area for keeping at least five days of feed consumption. Most village farmers in small-scale operations purchase all the feed required for one grow out. This is essential in remote regions, but farmers must store the feed in strong watertight bins, to reduce the risk of rodent attack and of mould and bacterial growth on the feed.

LITTER MANAGEMENT

Litter management is a crucial aspect of environmental management, and is fundamental to bird health and performance and to final carcass quality. If the litter is too hard, birds will develop lesions on the keel bone. If the litter is allowed to get wet, birds will develop foot lesions, and the associated high ammonia levels will cause respiratory problems and also affect the birds' immune system.

CHICK PLACEMENT MANAGEMENT

In village settings, it is normal to have multi-age flocks. However, it is best practice to place broiler chicks of the same age and flock source in a single house, and attempt to operate an "all–in, all-out" production system. Chicks must be carefully placed and evenly distributed near feed and water throughout the brooding area. If lights are available, they should initially be set at full intensity in the brooding area, to attract the chicks to the feed source. The first two weeks of a broiler chick's life are critical for its future growth.

UNIFORMITY

In large commercial operations, the average weight and uniformity of a flock are usually determined by taking a random sample of approximately 100 birds and recording their individual weights. Of the 100 birds weighed, the number that is within 10 percent of either side of the average body weight is used to calculate the uniformity, expressed in percentage terms. In a village broiler flock housed in a small enclosure it is important that the farmer identifies the birds that are underweight, and ensures that they have good access to feed and water.

Photo Credit: Robert Pym

Trough and chain automated system of feeding broilers

LIGHTING PROGRAMMES

In most village operations, lighting is not provided, although the amount and intensity of light affect broiler activity. Correct stimulation of activity during the first five to seven days of life is necessary for optimal feed consumption, digestion and immune system development. Reducing the energy required for activity during the middle part of the growing period improves production efficiency. Uniform distribution of light throughout the house is essential. It is recommended that 25 lux at chick height be used during the first week of brooding to encourage early weight gains. For optimum performance, light intensity at floor level should not vary by more than 20 percent. After seven days of age, light intensities should be diminished gradually to 5 to 10 lux.

CATCHING PROCEDURES

Feed should be withdrawn about eight to 12 hours before birds are sent to slaughter (Barnett *et al.,* 2001). The purpose of this is to empty the digestive tract and prevent ingested feed and faecal material from contaminating the carcasses during processing. It is important that farmers know the local or national regulations concerning the recommended time for feed withdrawal prior to slaughter.

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Housing and management of layers

Phil Glatz, *Pig and Poultry Production Institute, SARDI, Roseworthy 5371, South Australia, Australia*

CHICK MANAGEMENT

Modern hybrid layers can be reared successfully in floor and cage brooding systems in developing countries. However, they need more careful management than village chicks, which are better able to cope with temperature fluctuations. Prior to chick arrival, it is important to clean and disinfect the cages or the floor brooding area. The brooders should be set up the day before delivery, at 34 to 36 °C for cage brooding or 35 to 36 °C for floor brooding (Hyline International, 2009). Drinkers need to be full or the drinking system in operation, to encourage birds to drink. If nipple drinkers are used, the water pressure should be reduced so that birds can see the drop of water hanging on the drinker. Feed should be placed on paper if birds are reared in cages. Feeders on the floor should be filled and kept under high light intensity for 20 to 22 hours per day for the first week, to attract the birds.

GROWING PERIOD MANAGEMENT

The first 17 weeks of a pullet's life are critical. Careful management during this period will allow the bird to meet her performance potential (Bell and Weaver, 2001). Although it is not always possible to grow pullets in strict isolation from older birds on village farms, it is recommended on semi-commercial and commercial farms. During the first six weeks, it is important to provide feed at least twice a day. After five weeks, feed consumption and body weights must be checked. It is good practice to weigh 100 pullets a week during the growing period, beginning at five weeks of age. Pullets should be moved to cages or the laying house at 16 weeks of age, before the onset of sexual maturity.

FLOOR SYSTEMS MANAGEMENT

Perches should be provided in the growing and laying house environment. This allows the birds to develop their leg and flight muscles, which is essential for their full utilization of the laying house environment. Perches reduce the social stress of birds interacting on the floor, by providing them with a place to roost and get away from other birds in the flock. It is also desirable that birds have access to the same type of feeder and water system in the growing house as they will have in the laying house, although this is not always possible.

Birds also need to adapt to the presence of humans, and walking through a poultry house regularly will socialize them. In the laying period, the lighting times need to be synchronized with those in the rearing facility. When birds are placed in the laying house they need to be encouraged to explore the nest boxes. Commercial-scale operations can do this with nest lights to train the birds to use the nests.

Photo Credit: Robert Pym

Rearing layer pullets in multiple-bird wire cages

Photo Credit: Phil Glatz

Photo Credit: Olaf Thieme

Large-scale modern layer barn (above) and sector 2 layer production unit (Egypt, below)

LIGHTING PROGRAMME

The egg production of layers is very closely related to the changes in day length to which the pullets are exposed. Egg numbers, size and livability can be markedly influenced by the lighting programme (Lewis and Morris, 2006). An effective lighting programme for houses where outside daylight can be excluded involves giving pullets 20 to 22 hours of light a day at 30 lux in the first week, reducing this to 20 hours at 5 lux in the second week, and then reducing the photoperiod over the following weeks, to reach ten to 12 hours by seven to nine weeks of age.

In open-sided houses, lighting is increased to the longest natural day length from six to 17 weeks of age. It is useful to provide light stimulation when the body weight of commercial hybrids reaches about 1.5 kg. Light can be increased by 15 to 30 minutes per week, until 16 hours of light a day is reached. It is critical that light intensity in housing is increased to 10 to 30 lux. There should be no decrease in day length or light intensity for adult layers. In village poultry production, most birds are exposed to a natural day length, and farmers do not have lighting available to stimulate egg production in village hens.

In developing countries, layers are not generally reared or kept in light-controlled housing.

The onset of sexual maturity or egg production depends on reaching the minimum chronological age and a minimum body weight (usually about 1.5 kg in commercial hybrids), as well as having adequate nutrient intake to support production, and a constant or increasing day length of at least 12 hours.

An optional lighting technique for promoting increased feed consumption is night lighting. This involves turning the lights on for one hour in the middle of the dark period, to allow the birds to feed.

EGG SIZE MANAGEMENT

Egg size is largely genetically determined, but can be manipulated by lighting and feeding programmes. The larger the body weight at maturity, the larger the hen's eggs will be for her entire life. Egg weight is thus generally a reasonable indicator of body weight, but in general the earlier a flock begins production, the smaller the egg size will be, and the later the onset of egg production, the larger the egg size. Lighting programmes can be manipulated to influence rate of maturity (Bell and Weaver, 2001). A decreasing light pattern continuing past ten weeks of age delays maturity and increases average egg size. Egg size is greatly affected by the intake of energy, total fat, crude protein, methionine and cystine and linoleic acid. Levels of these nutrients can be increased to improve early egg size, and then gradually reduced to control egg size at later ages.

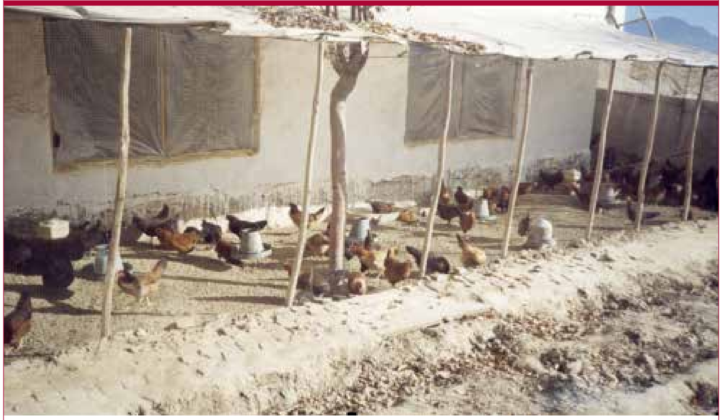
Photo Credit: Olaf Thieme

Semi-intensive sector 3 type layer production (Afghanistan)


Photo Credit: Robert Pym

Modern tier-step layer cages: the cages have automated watering, feeding and egg collection

MOULTING

Many producers practise induced moulting of the whole flock, which does not involve fasting of the birds. Commercial birds perform very well after a rest, particularly in the latter weeks of the moult cycle, when they achieve excellent shell quality and persistency. The optimum age for moulting is usually about 65 weeks.

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Management and housing of semi-scavenging flocks

Robert Pym, *School of Veterinary Science, The University of Queensland, Gatton, 4343, Queensland, Australia*

The large majority of families in rural regions of many developing countries own small household flocks of semi-scavenging poultry (mostly chickens), which often make significant contributions to poverty alleviation and household food security (Alders and Pym, 2009). However, the increasing density of human settlements has resulted in a decrease in the scavenging feed resource base (SFRB) in urban and peri-urban areas. This, combined with government action associated with the risks of disease transfer, particularly highly pathogenic avian influenza (HPAI), to humans and commercial poultry, is leading to a steady reduction in the number of peri-urban scavenging flocks of family poultry in many countries, and the large majority of these flocks are now located in rural regions.

Small (five to 30-bird) family-owned flocks, usually of indigenous breed or crossbred birds, are given household food scraps and sometimes small amounts of grain or grain by-products, and spend much of their time during daylight hours scavenging around the house and yard for seeds, insects, snails, earthworms, grass, shoots, fallen fruit, frogs, etc., depending on the local environment and season. Household scraps and supplementary grain typically comprise a significant proportion of the energy intake of these birds, particularly in the dry season (see website on Poultry feed availability and nutrition in developing countries). Birds are not usually provided with water, so have to obtain it from the environment. This can have a marked impact on their health and productivity, particularly in the dry season.

Photo Credit: Viengsavanh Phimphachanhvongsod

Semi-scavenging poultry production (Lao PDR)

Photo Credit: Joerg Henning

Household flock of scavenging chickens provided with nigh-time shelter under the human dwelling (Myanmar)

HOUSING

One of the defining features of the semi-scavenging production system is the lack of management compared with most other production systems (Gueye, 2000). The birds are very much on their own, and their productivity is usually quite limited by the typically meagre nutritional inputs they receive. Housing is mostly limited to some form of enclosure for the birds at night, to protect them from predation, theft and environmental exposure, and to provide a site for supplementary feeding. Enclosures also make it possible to catch birds for vaccination, although this is by no means a regular or common practice with semi-scavenging poultry. Birds' night shelters may be a separate structure, under the human dwelling, or even within their owner's home. However, it is not unusual for birds to be provided with no shelter, and to roost in trees at night. Where a separate structure is available, it is usually a simple construction made from local materials.

Indigenous breed birds are seldom reared or housed in confinement, as their productivity (egg and meat production), even under good-quality *ad libitum* feeding, is insufficient to warrant the cost of this level of management. Confinement rearing may be justified for some higher-producing indigenous strains or crossbreeds, where there is a niche market for their eggs or meat. Conversely, improved breed/strain commercial birds cannot perform at their genetic potential under semi-scavenging management conditions, so are not suitable for this form of production. The survival of commercial genotypes (particularly broilers) is severely compromised under scavenging systems.

Photo Credit: Filomena dos Anjos

Poultry house for overnight shelter (Mozambique)

Photo Credit: Eugene Lanada

House with woven banana-leaf nests for chickens under the eaves (Philippines)

EGG MANAGEMENT AND REPRODUCTIVE PERFORMANCE

Most rural families keeping small flocks of poultry provide the hens with nests; nests constructed of woven banana leaves or similar materials are very suitable and common in the wet tropics. These are often placed off the ground, to reduce problems with predation. The hen typically lays a clutch of ten to 15 eggs in the nest, and then sits on them. In some cases, the owner might take a number of eggs for eating or sale, but in most communities and cultures the majority of the eggs laid are left in the nest to be hatched by the hen. Most indigenous hens are excellent incubators, and typically ten chicks hatch from a setting of 12 eggs. However, in many cases, fewer than five of these will survive to six weeks of age, owing to predation, disease, malnutrition and climatic exposure.

MANAGEMENT INTERVENTIONS

In many countries, aid projects involving scavenging poultry flocks have demonstrated that it is possible to reduce chick attrition rates dramatically by practising confinement rearing of the chicks with the hen for the first week or two, supplemental feeding of the hen and creep-feeding of the chicks over this period, and regular vaccination of all birds in the flock, including chicks, against Newcastle disease (Henning *et al.,* 2009). These measures allow farming families to rear all surviving chicks to about six weeks, but the birds must also be provided with adequate nutrition from the SFRB or supplementary feeding until they are slaughtered or sold. If the SFRB is inadequate, and supplementary feed is either not available or is too expensive, the family has the option of setting fewer eggs under the hen, and either eating or selling the surplus. This is the most sustainable option in most situations, but may not be readily accepted in all cultures and communities.

Males surplus to requirements for breeding or cock fighting are kept for slaughter. Owing to high levels of chick attrition, this will often apply to only one or two birds per hatch. The large majority of village chicken strains in many developing countries grow slowly, even on relatively high levels of nutrition. Birds are typically slaughtered at about 1.0 to 1.5 kg live-weight at somewhere between 12 and 20 weeks of age. Management of these birds is usually the same as for the rest of the flock, receiving household scraps and small amounts of grain or grain by-products every day to supplement their scavenging. The use of larger-bodied crossbred birds can have deleterious consequences where feed inputs are restricted, as the growing birds may receive sufficient food to meet only their maintenance requirements. This also applies to larger-bodied laying hens, when egg production can suffer.

One of the major constraints to improving productivity in many regions is the limited availability of suitable prepared feed or feed ingredients for hens and young chicks in the first week or two following hatch. In these regions, considerable efforts are needed

Photo Credit: Eugene Lanada

Hen and young chicks kept in cages for the first two weeks post-hatch (Philippines) to identify suitable locally available ingredients and diets that provide the nutrients required by chicks and hens at this stage.

Photo Credit: Olaf Thieme

Improved chicken housing (Afghanistan)

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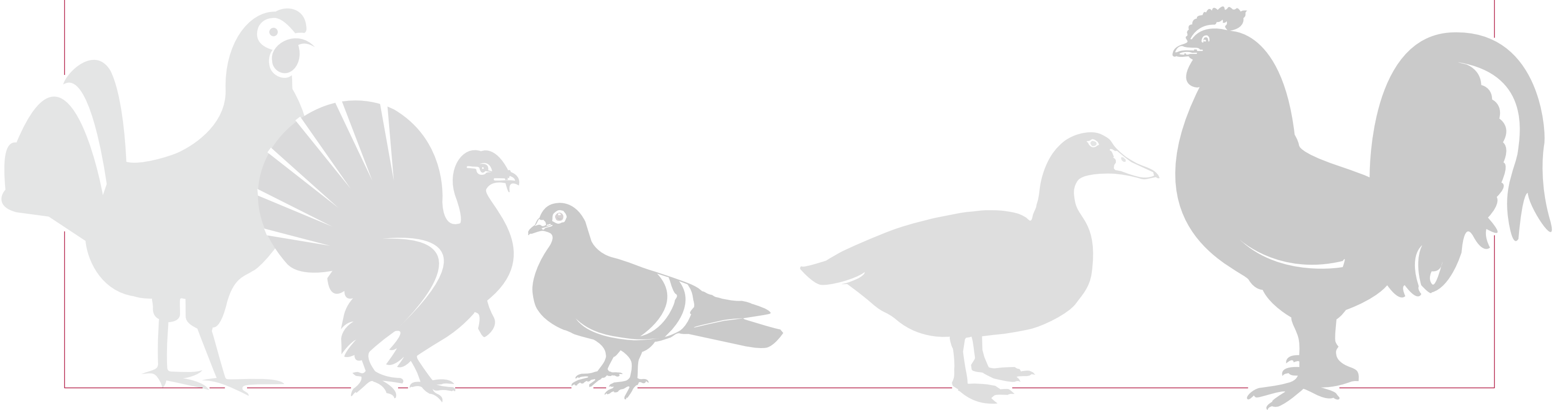
Poultry waste management in developing countries



Poultry waste management in developing countries

Charles Michael Williams*, North Carolina State University, Department of Poultry Science, Raleigh NC, United States of America*

INTRODUCTION

Poultry meat and eggs provide affordable, quality food products that are consumed by most ethnic populations worldwide. Advances in knowledge and technology over recent decades favour the growth and intensification of poultry production in developing countries where there are increasing human populations and economic constraints. Issues related to the environment, human health and the quality of life for people living near to and distant from poultry production operations make waste management a critical consideration for the long-term growth and sustainability of poultry production in larger bird facilities located near urban and peri-urban areas, as well as for smaller commercial systems associated with live bird markets, and for village and backyard flocks located in rural areas.

These information notes focus primarily on medium-sized to large intensive poultry production units, but many of the principles apply to smaller operations, including small family scavenging flocks. Fundamental knowledge of the environmental and health issues associated with poultry waste management will serve both small and large poultry producers now and in the future, as the intensification of poultry production continues to gain favour globally.

POTENTIAL POLLUTANTS AND ISSUES RELATED TO POULTRY PRODUCTION

The production of poultry results in: hatchery wastes, manure (bird excrement), litter (bedding materials such as sawdust, wood shavings, straw and peanut or rice hulls), and on-farm mortalities. The processing of poultry results in additional waste materials, including offal (feathers, entrails and organs of slaughtered birds), processing wastewater and biosolids. Most of these by-products can provide organic and inorganic nutrients that are of value if managed and recycled properly, regardless of flock size. However, they also give rise to potential environmental and human health concerns as the sources of elements, compounds (including veterinary pharmaceuticals), vectors for insects and vermin, and pathogenic microorganisms. With the probable exception of veterinary pharmaceuticals, these factors are also relevant to small flocks, including small family flocks that may be partially housed in containment structures.

Managing these poultry by-products as potential pollutants centres on water and air quality concerns, and in some cases on soil quality (FAO, 2008; Nahm and Nahm, 2004; Williams, Barker and Sims, 1999). Specific concerns that are well documented include degradation of nearby surface and/or groundwater, resulting from increased loading of nutrients such as nitrogen and phosphorus (and potassium in some locations). Air quality issues are less well understood and include the fate and effect of ammonia, hydrogen sulphide, volatile organic compounds (VOCs) and dust particulates emitted from poultry production facilities. Greenhouse gas emissions and health effects associated with nuisance odorants are also emerging and/or relevant issues, owing to global climate change and increasing human populations in close proximity to poultry operations, respectively.

Water and soil impacts of potential pollutants from poultry production

Most poultry manure and litter are applied to land near poultry production farms. With few exceptions, this is the preferred practice in developing countries and elsewhere. Such land management of poultry by-products brings the risk of surface and groundwater contamination from potential pollutants contained in the manure and litter. Its value depends on several factors, including the agronomic potential of the receiving crop(s) to utilize the waste nutrients, the receiving soil type and specific geological

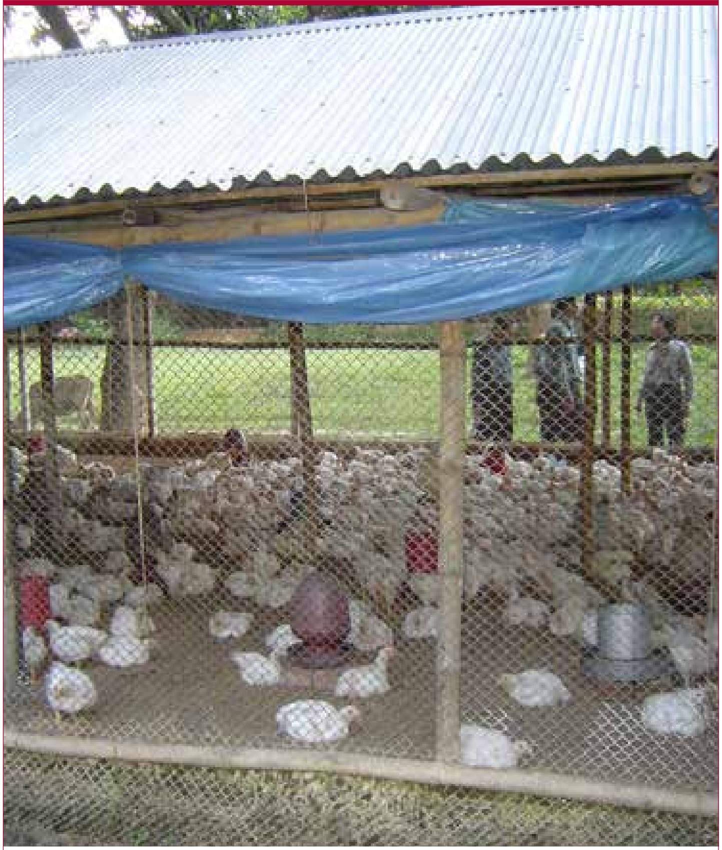


Photo Credit: John T. Brake

Housing conditions that promote good ventilation, non leaking waters and drier manure and litter results in healthier birds and manure of better nutrient value for crop fertilizer.

conditions of the land being utilized, the distance to nearby surface and groundwaters, the amount of vegetated areas (riparian buffers) adjacent to nearby surface waters, and the climate. Nutrient loading and build-up within a geological region is ecologically important and has an impact on the diversity and productivity of essential, naturally occurring living organisms within that region (Gundersen, 1992). The issue is increasingly complex owing to the trend for producing meat and eggs under intensified systems that require grain to be imported into production regions to meet feedstock requirements. This often leads to nutrient imbalances, and adverse environmental or health effects can occur when land application of the nutrients exceeds crop utilization potential, or if poor management results in nutrient loss due to soil erosion or surface runoff during rainfall. Surface or groundwater contamination by manure nutrients and pathogens is especially serious if drinking-water supplies are affected.

The primary nutrients of concern are nitrogen and phosphorus. The nitrogen compounds contained in manure and litter are very dynamic and can be removed from land by uptake of the receiving crop harvest or by conversion to gases that volatilize into the atmosphere in the form of ammonia, nitrous oxides or harmless di-nitrogen. Nitrogen is also very mobile in soil, and may be transported to groundwater and/or nearby surface waters. Unlike nitrogen, phosphorus in manure and litter is very immobile, but can leach into shallow groundwater or laterally transport to surface waters via erosion or subsurface runoff under certain climatic, soil and phosphorus concentration conditions. Nitrogen in the form of nitrates in drinking-water can cause adverse health effects; and both nitrogen and phosphorus in certain concentrations and environmental conditions can result in degradation of surface waters.

Regarding nutrient loading from poultry manure and litter, the focus is mainly on nitrogen and phosphorus, but certain metals such as copper and zinc, which may also be contained in poultry excreta, should also be considered when planning long-term sustainable nutrient balance in soils receiving poultry waste. In certain soil conditions, a build-up of these metals can be detrimental (toxic) for some crops (Zublena, 1994).

Air quality impacts of potential pollutants from poultry production

Air quality can be affected by aerial emissions of pollutants from poultry production facilities. Ammonia emitted into the atmosphere is arguably the most environmentally significant aerial pollutant associated with poultry production (FAO, 2006). The transport and fate of ammonia once it is emitted into the atmosphere are not well understood, but its presence in high concentrations can trigger environmental effects that have impacts on local ecosystems and human health. As such, consideration of the environmental effects on airsheds and watersheds of nutrient loading from poultry production is important for long-term sustainability. Ammonia from poultry operations is derived from nitrogen, which is an essential component of dietary protein, amino acids and other biomolecules necessary for life. However, dietary nitrogen not converted into meat, eggs or other tissue is excreted in the form of organic nitrogen, which is rapidly converted into ammonia under most, but not all, poultry production practices. The amount of ammonia actually emitted into the atmosphere depends on multiple variables, including climate, poultry housing design, and manure and litter storage and treatment practices, such as methods for applying them to land.

Hydrogen sulphide and other VOCs can result from the metabolic breakdown of poultry waste products, generally under low-oxygen conditions such as occur when manure is allowed to ferment (anaerobically digest) in a pit beneath the birds, in an earthen lagoon or in other open-air containment. This type of waste operation is more common with swine or dairy livestock than poultry, but may occur in some locations with layer operations. Under open-air fermentation, hydrogen sulphide and VOCs can be emitted into the atmosphere as pollutants, and can also be components of nuisance odour. Hydrogen sulphide can be dangerous to humans at certain concentrations. Donham and Thelin (2006) note that agitation of manure slurry in pits beneath animals can result in rapid elevation of ambient hydrogen sulphide to lethal concentrations, within seconds. The World Health Organization (WHO, 2000) notes an air quality guideline for hydrogen sulphide of 0.15 mg/m^3 averaged over a 24-hour period.

Particulate matter (or dust) is an aerial pollutant of more concern than hydrogen sulphide and VOCs. It occurs in typical poultry operations where appreciable numbers of birds are confined. Dust emissions can contain dried fecal matter and may include bacteria, endotoxins, moulds, mites and insect parts (Clark, Rylander and Larsson, 1983). Dust emissions from housing facilities are highly variable, depending on the climate, building design, feed consistency (dry or pellet) and control mechanisms for preventing large dust particles from leaving the area near the building – in recent years, considerable progress has been made in developing low-cost dust barriers to prevent dust dispersion (Poultry Science Association, 2009). Fine particulate matter (e.g., PM-fine) resulting from the conversion of ammonia gas in the atmosphere into ammonium salts can have greater consequences for human health, and is less likely to be mitigated by dust barrier approaches for preventing larger dust particles. This is another of the factors that make aerial ammonia emissions so important.

Climatic conditions play a very significant role in the impacts from aerial poultry pollutants, regardless of flock size. For example, excessively dry conditions, especially in litter, result in increased respiratory conditions affecting birds' productivity, while

Photo Credit: John T. Brake

Excessive dust on surfaces and equipment in poultry housing should be regularly cleaned to reduce environmentally harmful bio-aerosols.

excessively wet litter results in increased ammonia concentrations (and pathogenic microorganisms), which are also detrimental to productivity.

OPTIONS AND CONSIDERATIONS FOR POULTRY WASTE MANAGEMENT

The planning, construction and operation of poultry meat and egg operations of any size must consider issues associated with storing, managing and utilizing potential waste by-products. On a global scale, much research has been conducted on ways of recovering nutrients and value-added organic products from animal wastes, to improve agricultural efficiency and mitigate environmental impacts in their regions. Many systems and approaches can be successful if properly operated and maintained.

Land application of crop nutrients

Globally, poultry manure or litter has been applied to land to enhance crop production for centuries. When properly managed, this is an effective and beneficial option. Environmental pollution occurs when manure or litter is applied to the land in excess of the receiving crop's capacity to utilize the nutrients. Other factors that influence the environmental fate of the manure and litter applied include methods of collecting, storing, handling, treating, transporting and applying the waste by-products to the receiving land. For example, with non-liquid-flush systems, the poultry housing and manure storage area should be designed so that the manure and litter are kept as dry as possible, to minimize aerial emissions of gases and assist fly control. Manure and litter storage should be planned to prevent contact with rainfall or rain runoff. Land application should be based on the agronomic uptake of the receiving crop, accurate analysis of the nutrients contained in the manure (particularly nitrogen, phosphorus, copper and zinc) and properly calibrated application methods; it should be avoided when the land is frozen or excessively wet. Land application methods that incorporate the manure or litter directly into the soil minimize odour and gas emissions and surface runoff. These principles also apply to small family operations, whose sanitation will be improved by periodically removing manure or litter from areas where just a few birds are housed, and by storing, composting and/or land-applying the product at least 100 m from where the live birds are kept.

Composting is a natural aerobic biological process to breakdown organic matter, which provides a practical and economically feasible method for stabilizing poultry manure and litter before land application (Carr, 1994). Correctly managed composting effectively binds nutrients such as nitrogen and phosphorus in organic forms, and reduces pathogens, insect eggs and weed seed owing to the heat generated during the biological processing. Composting can also reduce nuisance odour emissions from poultry waste storage and treatment areas. A variety of composting approaches, from very simple to more complex automated systems, are available for both large and small poultry producers.

In areas where manure or litter is land-applied near streams or surface waters, an exceptionally simple and effective approach for mitigating surface runoff or the subsurface flow of potential harmful nutrients is to maintain a natural riparian buffer next to the water resources (Wenger, 1999). Riparian buffers may comprise native grasses, shrubs or trees, or a combination of these. The width and make-up of a riparian buffer are specific to its location, and the width of the buffer from the stream edge determines its effectiveness. Natural grass buffers of approximately 10 m wide have been shown to reduce nitrogen and phosphorus from field surface runoff by approximately 25 percent, while combined grass and tree buffers are much more effective. This practice is a documented inexpensive natural method of protecting water resources from the nutrients and pathogenic microorganisms contained in nearby land-applied poultry manure or litter.

Animal refeeding

Scientific research has documented that nutrients and energy from poultry waste by-products, including manure and litter, can be safely recycled as a component of livestock and poultry diets when pathogens are neutralized (McCaskey, 1995). Poultry litter has been estimated to be as much as three times more valuable as a feedstuff than as a fertilizer for crop nutrients. However, such practices depend on regional regulations and public perceptions of the concept of animals' consumption of fecal material, regardless of its documented value and safety. If practised, caution is essential. For example, copper toxicity can result when litter is fed to sheep. Incorrectly processed poultry waste can contain potentially pathogenic microorganisms, including *Salmonella*. Depending on environmental conditions and the global region of production, antibiotics, arsenicals and mycotoxins can also be present in poultry manures and litters.

The refeeding of poultry processing by-products is a common and acceptable practice in most, but not all, cultures. Advances in the treatment and processing of feathers and offal to produce value-added feed ingredients are making this practice more attractive in some regions, especially with the recent increases for feeds derived from grains.

Bioenergy production

Poultry manure and litter contain organic matter that can be converted into bioenergy under certain processing technologies. One of the most common approaches for poultry excrement managed by water flushing (e.g., some layer operations) is anaerobic digestion, which yields biogas, a gas mixture with varying concen-


Photo Credit: John T. Brake

Manure from this facility can improve the nearby grass yield for grazing cattle when properly managed.

trations of combustible methane (FAO/CMS, 1996). The biogas can be used as an on-farm energy source for heat or as a fuel for various engines that generate electricity. An additional advantage is that, depending on processing conditions, anaerobically digested manure solids and liquids are further stabilized and more acceptable and safe for use as a fertilizer or feed supplement. Numerous technologies and approaches are available for on-farm or centralized anaerobic digestion, and all are influenced by multiple variables that affect biogas yield and efficiency – operational feasibility and effective management are critical to the success of this process, especially with some of the more complex anaerobic digester technologies. Unfavourable economic and other issues associated with operational feasibility, and low biogas yield from litter-based systems have discouraged many poultry producers worldwide from implementing this technology.

Poultry litter and dry manure can be incinerated for on-farm production of heat in small furnaces, or transported to central locations where they are combusted on a large scale for the generation of electricity. For both approaches, the amount of energy produced depends on the efficiency of the equipment utilized and the moisture content of the manure or litter burned. Operational feasibility and emission issues also affect this process, especially for on-farm small conventional furnaces.

Gasification technology is a way of producing bioenergy that is receiving renewed interest for small on-farm systems and central electric power stations in some regions. The process involves incomplete combustion in a limited-oxygen environment. As noted for both anaerobic digester technology and incineration units, economic costs and returns, operational feasibility and emission issues have an impact on the implementation of this technology. However, increasing energy costs, environmental policy related to mandated renewable energy production goals in some regions, and the evolving carbon credit market are stimulating interest in all technologies for processing poultry and other waste products that yield bioenergy and reduce greenhouse emissions.

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Poultry manure characteristics

***Charles Michael Williams**, North Carolina State University, Department of Poultry Science, Raleigh NC, United States of America*

INTRODUCTION

Knowledge of the amounts and compositions of manure and litter produced under different poultry production practices is essential for efficient and environmentally responsible management of these by-products as fertilizer, animal feed components or fuel. This knowledge is also required for the effective planning, implementation and operation of a waste management system that is appropriate for the number and type of birds in a given environment.

MANURE QUANTITY

Manure quantity and characteristics are influenced by the species, age, diet and health of the birds and by farm management practices. Estimates of the manure excreted by 1 000 birds per day (based on average daily live weights during the birds' production cycle) are approximately 120 kg for layer chickens, 80 kg for meat chickens, 200 to 350 kg for turkeys (grower females and grower heavy males, respectively), and 150 kg for ducks (Collins *et al*., 1999; Williams, Barker and Sims, 1999). Extrapolations can be calculated to give general estimates for the number of birds in a given operation.

After excretion, the quantity of manure requiring management depends on factors such as water content, whether the manure is stored in a location where rainfall collects, or whether it is mixed with materials such as straw, wood shavings or rice hulls, as is typical in meat bird housing. Estimates of the litter produced by 1 000 meat birds produced for market range from 1.1 to 2.4 tonnes for chickens, 7.3 to 12.7 tonnes for turkeys (grower females and grower heavy males, respectively), and 3.9 tonnes for ducks (Collins *et al*., 1999; Williams, Barker and Sims, 1999). Again, extrapolations can be calculated to give general estimates for the number of birds in a given operation. However, these values can be greatly influenced by management practices, such as whether fresh litter is added to existing litter after each growing cycle of birds, or a portion of the manure "cake" is removed from the existing litter prior to adding fresh litter.

Photo Credit: John T. Brake

Good ventilation and manure collection which separates the birds from the manure should promote better bird health and performance

MANURE NUTRIENTS

The scientific literature contains reliable and comprehensive information based on average values from a wide database, on the chemical (nutrient) and physical composition of manures and litter (see the references at the end of this note). Estimates of some environmentally important nutrients in manure are given in Table 1. They can vary according to the composition of ingredients in the birds' feed, and especially if the birds scavenge for all or part of their diet. Although the estimated manure weight as excreted may not vary significantly by bird type, it is essential that specific manure nutrient characteristics and concentrations be determined by reliable sampling and testing.

Manure and litter storage conditions influence some nutrient concentrations; for example, appreciable ammonia may be lost to the atmosphere from manure or litter that is stored in areas exposed to rain or groundwater. Storage in such conditions is not

TABLE 1

Estimates of nutrient contents of chicken manure and litter (kg/tonne manure excreted)

	Nitrogen	Phosphorus (as phosphorus pentoxide)	Copper	Zinc
Layer chicken manure	13.5	10.5	0.01	0.07
Meat chicken manure	13.0	8.0	0.01	0.04
Broiler litter	35.5	34.5	0.26	0.36

Photo Credit: John T. Brake

Good manure management should also include considerations for biosecurity. Preventing contact with birds of differing species and other animals should be a part of good management practices.

environmentally sound, nor is it an efficient way of conserving nitrogen to be utilized for crop growth. The phosphorus content will not change significantly under such increased moisture conditions. To ensure agronomic balance and environmental management that prevent the overapplication of nutrients, it is therefore important to coordinate sampling activities with the timing of land application for maximum crop yields, rather than relying solely on established values or those measured when the manure was in the production house or during early storage. It is also very important to estimate the availability of the crop nutrients in manure or litter (Shaffer, 2009).

MANURE MICROORGANISMS AND VETERINARY PHARMACEUTICALS

Poultry manure and litter contain populations of naturally occurring microorganisms, many of which are environmentally beneficial and play important roles in the ecological nutrient cycles associated with carbon, nitrogen, phosphorus, sulphur and other elements in poultry by-products. However, depending on management and environmental conditions, poultry manure and litter can also contain harmful pathogenic microorganisms that affect human health. Chemical residues in the form of veterinary pharmaceuticals (antibiotics, coccidiostats and larvicides) may also be contained in poultry manure and litter (Sims and Wolf, 1994), depending on diet formulation, management practices and the regulation of poultry production enterprises in a given region. Accurate sampling and laboratory analyses of the harmful microorganisms and chemical residues contained in manure and litter are critical to the implementation of effective mitigation practices.

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Aerosol contamination

Charles Michael Williams*, North Carolina State University, Department of Poultry Science, Raleigh NC, United States of America*

INTRODUCTION

Aerosol contamination from poultry production can generally be characterized as pollutants, including gases (such as ammonia), particulates (dust) and microbial pathogens suspended in the airspace within and transported from the birds' housing or containment areas. Dust from poultry operations can include feed dust, manure, feather dust, bacteria, mould spores, endotoxins, insects, insect parts and ammonia absorbed in dust. The transport of aerosols can be an important consideration when establishing the separation distances between poultry production facilities to reduce the risk of aerial transmission of communicable disease-transmitting microorganisms. Depending on their concentration, aerosol pollutants can be harmful to the respiratory health of birds within the containment areas, and may also be harmful to the health of workers or inhabitants living close to poultry production areas. However, at the international level, comprehensive studies regarding the human health effects of aerosols from poultry operations are lacking.

Aerial-transported ammonia can affect local and distant ecosystems, depending on the ecological sensitivity of the water source(s) into which the ammonia is deposited as dry or wet fall. Aerosol ammonia is also a precursor gas for ambient particulate matter, under certain atmospheric conditions, and there is evidence of negative human health effects from exposure to particulate matter, especially fine particulate matter.

Regardless of their location or size, existing and new poultry production operations should consider mitigating the risks associated with aerosol emissions to ensure the future sustainability of poultry production practices.

SOURCE AND EMISSION OF AEROSOLS

Even under the best management conditions, poultry production can be a source of aerosol contaminants, including gases, odour, dust and microorganisms. These gaseous compounds and living organisms are generated from natural biological processes associated with poultry manure decomposition soon after the manure is produced, during manure and litter storage and treatment, and during application of the manure or litter to fertilize cropland. Particulate matter as dust can originate from both feed and the birds. However, the generation rate of these gases, microorganisms and particulates is highly variable, depending on the weather, the species and age of the birds, housing conditions, and the manure handling system, feed type and management system(s) used.

Once aerosol pollutants are generated, they can be emitted from their sources through the production unit's ventilation system, which is characteristic of larger units, or by natural weather-sourced ventilation, in smaller or naturally ventilated larger units. The emission rates of the pollutants depend on many factors including time of year and day, temperature, humidity, wind speed and other weather conditions, ventilation rates, housing type, and manure properties and characteristics – for example, dryer manure and litter result in more particulate emission, while moist conditions are likely to result in increased emission of ammonia. It is extremely difficult to determine specific aerosol emission rates from point sources such as poultry housing units, manure or litter storage areas, and during application to cropland, and definitive information is lacking. This remains a very active area of research in many parts of the world.

EFFECTS OF AEROSOL POLLUTION

Aerosol emissions can compromise bird health and productivity (feed conversion, meat and egg yield). Aerosol emissions from poultry operations can transmit communicable diseases to neighbouring poultry flocks; scientific evidence shows that some pathogenic microorganisms can remain viable and be transported for appreciable distances (from 50 to more than 500 m) in ambient air. Evidence also shows that the health of farm workers can be affected by day-to-day exposure to aerosols. Primary effects are on respiratory function, which is not surprising considering the composition of typical aerosol pollutants associated with poultry production (ammonia, dust, microorganisms and endotoxins).

Clean housing surfaces, good ventilation and good management will reduce risks caused by bio-aerosols in poultry houses.

Photo Credit: John T. Brake

An aerosol of particular ecological and human health importance is ammonia. A growing body of evidence shows that appreciable concentrations of ammonia are released from poultry (and livestock) production operations; increases in nitrogen concentration resulting from wet and dry atmospheric deposition of ammonia are having serious impacts on some ecosystems globally (resulting in decreased forest productivity, increased nitrate concentrations in surface and groundwaters, and increased risk of eutrophication); and ammonia is a precursor gas for the formation of ambient fine particulate matter (human exposure to elevated fine particulate matter has been linked to a variety of adverse health effects, including acute respiratory conditions and increased mortality risks).

MITIGATING THE RISKS OF AEROSOL POLLUTION

The most effective strategy for reducing aerosol pollution is to reduce its source. Management strategies such as improving hygiene in poultry production buildings (by constructing them so that they do not encourage dust build-up), controlling manure and litter moisture, and formulating feeds to reduce nitrogen in the excreta all help decrease aerosol concentrations. Technologies such as biofilters and/or bioscrubbers as components of point source ventilation exhausts are not economically practical in developing and many developed countries. Farm workers can reduce health risks by practising good hygiene and wearing protective eye shields and dust masks when possible and practical, especially in dusty poultry production environments.

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Location, siting and concentration of poultry units

Charles Michael Williams, *North Carolina State University, Department of Poultry Science, Raleigh NC, United States of America*

INTRODUCTION

Worldwide, most segments of animal production, including poultry, are increasingly affected by regulations, policy and public perceptions. There is increased attention to and awareness of the environmental and human health impacts – real or perceived – of animal agriculture. The demand for poultry meat and eggs will likely increase in the next decades, but in most parts of the world, the proportion of the population participating in day-to-day on-farm activities is steadily decreasing – a trend that is likely to continue. Although small backyard and scavenging poultry flocks are becoming more popular in some urban areas of developed countries, global demand for production and economic efficiency are likely to result in larger concentrated production farms continuing to be more prevalent in most regions.

Small and scavenging flocks controlled by cooperatives, villagers and families are prevalent in rural areas of some developing countries, where they contribute to poverty alleviation and food security. However, as larger production farms become more common in these countries, siting issues regarding biosecurity will have an impact on small-scale village and family flocks, possibly leading to conflict if proper management practices are not exercised. The sustainability and potential expansion of any poultry production or processing operation are affected by its location, especially in the long term. This is particularly true of operations located near urban or peri-urban areas. These factors demand careful planning of the location and siting of poultry production units. Failure to take such planning considerations into account when constructing new and larger facilities may result in costly changes or management expenditures in the future.

Photo Credit: John T. Brake

This poultry facility has good topography for rain drainage away from the building, utilities, fencing for bio-security, and appears to be located away from nearby residents– all good siting practices.

PLANNING CONSIDERATIONS

Infrastructure, water, regulatory requirements and permits

A first step in planning the location of any poultry unit includes assessing the existing infrastructure support, especially for larger units; for example, does the location have adequate roadways and utilities to support the transport of inputs and outputs and ensure the unit's energy requirements? The adequacy and supply of fresh and safe water to support the unit's production and operational needs should also be determined. The available labour force should be considered: larger farms need dependable workers, who should – as far as possible – live in areas without potential disease reservoir birds (village and scavenging flocks). The regulatory requirements for the region must be accurately assessed. These may involve setback stipulations from property lines, water sources, residences, roadways, schools and churches; development and implementation of comprehensive nutrient management plans that apply to the watershed or airshed in which the unit will be located; and acquisition of necessary permits.

Near neighbour assessment

The potential for affecting neighbours or neighbourhoods with nuisance emissions (primarily odour) and/or flies cannot be ignored. The management and operational efficiency of any operation can be negatively affected if sufficient time and effort are not given to resolving conflicts resulting from nuisance complaints and potential litigation, even if all regulatory and permit requirements are met. With few exceptions, the transport of potential pollutants (by surface runoff, leaching into the groundwater, or aerial emissions of volatile compounds or dust particulates) from poultry production or processing is not limited to the boundaries of the property on which the unit is located; neither is communicable disease transmission. Consideration should be given to biosecure zones, especially in developing countries, regarding separation distances from areas containing water sources supporting water fowl, nomadic ducks or village birds, which are all potential carriers of avian influenza and other diseases. Serious consideration must also be given to communication and interaction with near neighbours. Assessment of how the unit will be received (or perceived) by its neighbours should be a component of site location planning.

Specific considerations

The following are important considerations for the successful siting of a poultry operation:

- Topography and soil type, which have an impact on rain runoff patterns: Avoid areas that will not support adequate drainage, and those that are subject to flooding.
- Prevailing wind patterns relative to emissions from poultry house ventilation fans and distance to near neighbours: The distance should be sufficient to ensure that odours and dust dissipate before they reach the neighbours. Tree buffers have been effective in mitigating dust and odour emissions from poultry facilities; it is recommended that production buildings be sited in areas that contain or would support such vegetative buffers.
- Future expansion plans: Is there sufficient land area to support future expansion without affecting near neighbours and/or becoming land-limited for the application of manure and litter for waste management?
- Land area and crop type for agronomic uptake of land-applied manure and litter: Is there sufficient land for waste management practices? (Consult the references for estimates of manure and litter concentrations and characteristics.) Avoid areas where fields already contain high concentrations of less mobile nutrients such as phosphorus, copper and zinc; avoid areas in sensitive watersheds, if at all possible. Are surface water streams close to the land area that will receive manure and litter? If so, can riparian buffers be established along the stream boundary (if not already in place)?
- Visibility of the unit to public view.
- Potential for implementing robust vegetative buffers at appropriate distances from the poultry house ventilation fans to reduce dust and odour emissions.

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Slaughterhouse wastes

***Charles Michael Williams**, North Carolina State University, Department of Poultry Science, Raleigh NC, United States of America*

INTRODUCTION

Slaughterhouse wastes from poultry processing include processing water and organic solid by-products. This is also true of very small-scale processing facilities and village and home (backyard) flock operations. The World Bank Group (2007) provides detailed and useful environmental health and safety guidelines for all steps of poultry processing, from the reception of live birds, through slaughter and evisceration, to simple waste processing. This information note focuses on the utilization of organic solids, of which an estimated 1 million tonnes are generated every year worldwide. As for poultry production wastes (manure and litter), these organic solids should be considered both potential resources and potential environmental pollutants, depending on how they are processed and managed. Similarly, the siting of slaughterhouses, like that of production facilities, should give careful consideration to biosecurity and near neighbour issues. The size of the slaughter facility also has implications for environmental and food safety practices and issues – again, the size issue is similar for poultry production facilities.

The treatment and environmental fate of processing wastewater and organic solid wastes should be based on site-specific requirements, regulations and the location of the slaughterhouse. For example, some regions have very specific requirements for the organic and inorganic wastes that are discharged into surface waters following treatment, and some have restrictions or regulations for the processed solids destined for animal feed components. When possible, the treatment of solid waste should aim to produce value-added sellable by-products, such as animal or aquaculture feed components, energy (through biogas production) and agricultural fertilizer. For very small or backyard flock operations, slaughter is likely to generate very small quantities of solid wastes, and the management of these wastes should focus more on proper disposal and recycling (burial or composting) regarding biosecurity and human health issues.

COMPOSITION, CHARACTERIZATION AND REPROCESSING OF SLAUGHTERHOUSE SOLIDS

Poultry carcass yields are typically about 70 to 75 percent of the live bird weight; the quantity of potentially sellable solid waste depends on the efficiency of the processing methods and the health of the birds prior to processing.

Blood is approximately 2 percent of the live bird weight, and a source of highly concentrated protein when filtered and dried to produce blood meal. During slaughter, blood is typically collected separately from the other viscera and, depending on cooling conditions and storage time prior to further processing, may require chemicals to prevent coagulation. Processed blood meal can be used in animal and fish feed as well as fertilizer.

Feathers comprise approximately 7 to 10 percent of the live bird weight and are another source of protein (75 to 90 percent crude protein), although the utilization value of feathers as an animal feed component depends on further processing methods (e.g., high-pressure cooking at > 100 OC or enzymatic treatment) to improve digestibility. Processed feathers can also be used for bedding, clothing and other niche market items for humans.

The head, feet (recovered for human consumption in some regions) and inedible viscera make up the remainder of slaughterhouse solids. Following further processing by methods such as conventional rendering at specified temperatures and pressures, depending on the intended fate and risk factor of the material, sellable products in the form of protein-rich meals and fat are produced. Extensive further processing of these by-products may not be required in some areas, if biosecurity precautions are taken. For example, high-quality inedible viscera wastes are in great demand for intensive fish culture in some regions, and may require only simple on-farm grinding and mixing with a binder prior to use.

Regardless of location, before reprocessing, slaughterhouse solids can be broadly characterized as low-risk material originating from healthy birds, and high-risk material that may transmit disease to humans, livestock or poultry. For example, high-risk material would originate from birds that died from causes other than slaughtering, or birds or bird parts condemned as unfit for human consumption. Birds confirmed or suspected of carrying transmittable disease, especially a disease such as highly pathogenic avian influenza (HPIA), should be characterized as high-risk material. Care and management steps should be taken to keep high-risk materials separate from low-risk materials, as mixing of the two results in the entire batch being classified as high-risk. This is important not only for health and safety precautions but also for economic reasons related to the additional processing requirements for high-risk versus low-risk materials. The treatment of high-risk material intended for animal feed or fertilizer is typically an energy-intensive rendering or alternative heat treatment process, whereas reprocessing of low-risk material may include less stringent methods to make use of the solids for animal or aquaculture feed. For materials that are not suitable for processing into the food chain, alternative methods to be considered include approved burial, aerobic composting or treatments for energy production and/or processing for use as agricultural fertilizers.

The utilization of slaughterhouse solid by-products for animal feed is becoming increasingly restricted in many parts of the world. In such areas, anaerobic digestion – the biological degradation of organic matter into methane under anaerobic conditions – is an alternative that provides an opportunity for energy recovery and, depending on the type of anaerobic digestion employed, for reducing pathogenic microorganism in the solid substrate digested. Properly managed, anaerobic digestion can also reduce nuisance odours associated with slaughterhouse wastes, and conserve the non-carbon nutrient components in the digested material, which can be recovered for fertilizer or possible feed use. Salminen and Rintala (2002) provide a comprehensive review and relevant information to determine the applicability of anaerobic digestion and material recovery from poultry slaughterhouse waste.

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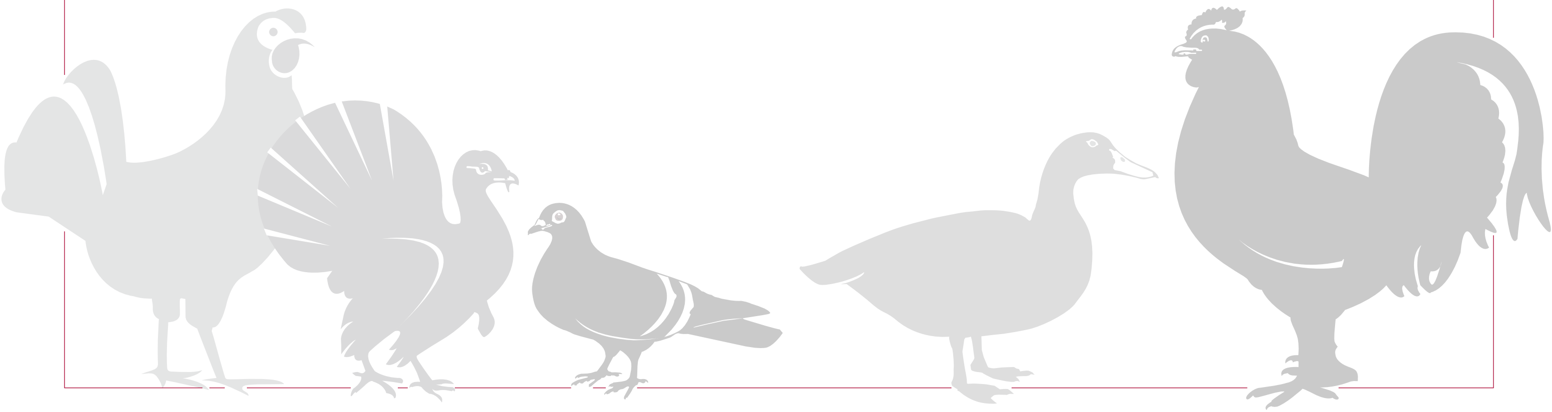
Poultry feed availability and nutrition in developing countries



Poultry feed availability and nutrition in developing countries

Velmurugu Ravindran, *Monogastric Research Centre, Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand*

Worldwide, production of poultry meat and eggs has increased consistently over the years, and this trend is expected to continue. It is predicted that most increases in poultry production during the next two decades will occur in developing countries, where rapid economic growth, urbanization and higher household incomes will increase the demand for animal proteins. Several factors have contributed to the consistent growth in world poultry production, including: i) genetic progress in poultry strains for meat and egg production; ii) better understanding of the fundamentals of nutrition; and iii) disease control. For example, the age for a meat chicken to reach the market weight of 2 kg has steadily decreased from 63 days in 1976 to 35 days in 2009, and the efficiency of converting feed into poultry products also continues to improve. This growth in poultry production is having a profound effect on the demand for feed and raw materials. Feed is the most important input for poultry production in terms of cost, and the availability of low-priced, high-quality feeds is critical if poultry production is to remain competitive and continue to grow to meet the demand for animal protein.

PRODUCTION SYSTEMS AND FEEDING

Historically, the poultry sector has evolved through three phases: i) traditional systems, which include family poultry consisting of scavenging birds and backyard raising; ii) small-scale semi-commercial systems; and iii) large-scale commercial systems. Each of these systems is based on a unique set of technologies. They differ markedly in investment, type of birds used, husbandry level and inputs such as feeds. The feed resources, feeding and feed requirements required to raise poultry also vary widely, depending on the system used.

The traditional system is the most common type of poultry production in most developing countries. Possible feed resources for the local birds raised in this system include: i) household wastes; ii) materials from the environment (insects, worms, snails, greens, seeds, etc.); iii) crop residues, fodders and water plants; and iv) by-products from local small industrial units (cereal by-products, etc.). The survival and growth of extensive poultry systems are determined by the competition for feed resources in villages. This system works well where biomass is abundant, but in areas with scarce natural resources and low rainfall, the competition for natural resources with other animals can be extreme.

Between the two extremes of traditional and commercial production systems is the semi-commercial system, which is characterized by small to medium-sized flocks (50 to 500 birds) of local, crossbred or "improved" genotype stock, and the purchase of at least part of their feed from commercial compounders. Several feeding strategies may be used in this system: i) on-farm mixing of complete rations, using purchased and locally available feed ingredients; ii) dilution of purchased commercial feeds with local ingredients; and iii) blending of a purchased concentrate mixture with local ingredients or whole grains.

The large-scale commercial system is the dominant production system in developed countries, and this sector has also recently expanded in many developing countries. Commercial systems are characterized by large vertically integrated production units and use high-producing modern strains of birds. In these systems, feed is the most important variable cost component, accounting for 65 to 70 percent of production costs. High productivity and efficiency depend on feeding nutritionally balanced feeds that are formulated to meet the birds' nutritional requirements.

POULTRY NEED TO BE FED WELL-BALANCED DIETS

Most poultry species are omnivores, which in nutritional terms means that they have a simple digestive system with non-functional caeca. Exceptions to this general rule include geese and ostriches, which have well-developed functional caeca. The digestive tract of poultry has more organs but is shorter than that of other domestic animals. The unique features of this digestive tract include the crop, which is a storage organ, and the gizzard, which is a grinding organ. In fast-growing meat chickens, it takes less than three hours for feed to pass from mouth to cloaca and for nutrients to be digested and absorbed. To compensate for the relatively short digestive tract and rapid digesta transit time, high-performing birds need easily digested, nutrient-dense diets. Nutrient balance is critical.

The rates of genetic change in growth and feed efficiency over the years have also changed the physiology of the birds. Nutrient requirements and nutritional management have therefore changed to satisfy the genetic potential of the new strains. The high genetic potential of current poultry strains can only be achieved with properly formulated feeds that are protein- and energy-dense. Poultry, especially growing birds, are unique among domestic animals in that any change in nutrition is reflected in bird performance almost immediately. This phenomenon has been successfully exploited by the commercial poultry industry to improve growth, carcass yield and egg production.

The term "poultry" encompasses a range of domesticated species, including chickens, turkeys, ducks, geese, game birds (such as quails and pheasants) and ratites (emus and ostriches). This overview does not discuss the nutrition of all these species, but focuses on chickens, which constitute more than 90 percent of the poultry market. However, the principles of nutritional management for chickens are generally applicable to other poultry species grown for meat and eggs.

NUTRIENT REQUIREMENTS

For maximum growth and good health, intensively reared poultry need a balanced array of nutrients in their diet. The nutrients required by birds vary according to species, age and the purpose of production – whether the birds are kept for meat or egg production. Table 1 provides a summary of recommended minimum levels of selected nutrients for meat chickens of different ages and for layers. To meet these specific needs, different classes of poultry have to be fed different types of diets. These recommendations should only be considered as guidelines and used as the basis for setting dietary nutrient concentrations in practical diets. Historically, recommendations on nutrient requirements have been based on available literature and data from expert groups. Currently, however, because each specific genotype has its own requirements, most commercial feed formulations use minimum requirements recommended by the breeding companies that supply the chicks.

Poultry require nutrients to maintain their current state (maintenance) and to enable body growth (weight gain) or egg production. Birds need a steady supply of energy, protein, essential amino acids, essential fatty acids, minerals, vitamins and, most important, water. Poultry obtain energy and required nutrients through the digestion of natural feedstuffs, but minerals, vitamins and some key essential amino acids (lysine, methionine, threonine and tryptophan) are often offered as synthetic supplements.

Energy

Poultry can derive energy from simple carbohydrates, fat and protein. They cannot digest and utilize some complex carbohydrates, such as fibre, so feed formulation should use a system based on available energy. Metabolizable energy (ME) is the conventional measure of the available energy content of feed ingredients and the requirements of poultry. This takes account of energy losses in the faeces and urine.

TABLE 1

Recommended minimum nutrient requirements of meat chickens and laying hens, as percentages or units per kilogram of diet (90 percent dry matter)

		Meat chickens			**Laying hens**
Nutrient	**Unit**	**0–3 weeks**	**3–6 weeks**	**6–8 weeks**	
Metabolizable energy	kcal/kg	3 200	3 200	3 200	2 900
	MJ/kg	13.38	13.38	13.38	12.13
Crude protein	%	23	20	18	15
Amino acids					
Arginine	%	1.25	1.10	1.00	0.70
Glycine + Serine	%	1.25	1.14	0.97	-
Histidine	%	0.35	0.32	0.27	0.17
Isoleucine	%	0.80	0.73	0.62	0.65
Leucine	%	1.20	1.09	0.93	0.82
Lysine	%	1.10	1.00	0.85	0.69
Methionine	%	0.50	0.38	0.32	0.30
Methionine + Cysteine	%	0.90	0.72	0.60	0.58
Phenylalanine	%	0.72	0.65	0.56	0.47
Phenylalanine + Tyrosine	%	1.34	1.22	1.04	0.83
Threonine	%	0.80	0.74	0.68	0.47
Tryptophan	%	0.20	0.18	0.16	0.16
Valine	%	0.90	0.82	0.70	0.70
Fatty acid					
Linoleic acid	%	1.00	1.00	1.00	1.00
Major minerals					
Calcium	%	1.00	0.90	0.80	3.25
Chlorine	%	0.20	0.15	0.12	0.13
Non-phytate phosphorus	%	0.45	0.35	0.30	0.25
Potassium	%	0.30	0.30	0.30	0.15
Sodium	%	0.20	0.15	0.12	0.15
Trace minerals					
Copper	mg	8	8	8	-
Iodine	mg	0.35	0.35	0.35	0.04
Iron	mg	80	80	80	45
Manganese	mg	60	60	60	20
Selenium	mg	0.15	0.15	0.15	0.06
Zinc	mg	40	40	40	35

Source: Adapted from National Research Council, 1994.

Birds eat primarily to satisfy their energy needs, provided that the diet is adequate in all other essential nutrients. The energy level in the diet is therefore a major determinant of poultry's feed intake. When the dietary energy level changes, the feed intake will change, and the specifications for other nutrients must be modified to maintain the required intake. For this reason, the dietary energy level is often used as the starting point in the formulation of practical diets for poultry.

Different classes of poultry need different amounts of energy for metabolic purposes, and a deficiency will affect productive performance. To sustain high productivity, modern poultry strains are typically fed relatively high-energy diets. The dietary energy levels used in a given situation are largely dictated by the availability and cost of energy-rich feedstuffs. Because of the high cost of cereals, particularly maize, the use of low-energy diets for poultry feeding is not uncommon in many developing countries.

Protein and amino acids

The function of dietary protein is to supply amino acids for maintenance, muscle growth and synthesis of egg protein. The synthesis of muscle and egg proteins requires a supply of 20 amino acids, all of which are physiological requirements. Ten of these are either not synthesized at all or are synthesized too slowly to meet the metabolic requirements, and are designated as *essential* elements of the diet. These need to be supplied in the diet. The balance can be synthesised from other amino acids; these are referred to as *dietary non-essential* elements and need not be considered in feed formulations. From a physiological point of view, however, all 20 amino acids are essential for the synthesis of various proteins in the body. The essential amino acids for poultry are lysine, methionine, threonine, tryptophan, isoleucine, leucine, histidine, valine, phenylalanine and arginine. In addition, some consider glycine to be essential for young birds. Cysteine and tyrosine are considered semi-essential amino acids, because they can be synthesized from methionine and phenylalanine, respectively. Of the ten essential amino acids, lysine, methionine and threonine are the most limiting in most practical poultry diets.

Poultry do not have a requirement for protein *per se*. However, an adequate dietary supply of nitrogen from protein is essential to synthesize non-essential amino acids. This ensures that the essential amino acids are not used to supply the nitrogen for the synthesis of non-essential amino acids. Satisfying the recommended requirements for both protein and essential amino acids therefore ensures the provision of all amino acids to meet the birds' physiological needs. The amino acid requirements of poultry are influenced by several factors, including production level, genotype, sex, physiological status, environment and health status. For example, high levels of lean meat deposition require relatively high levels of lysine. High levels of egg output or feather growth require relatively high levels of methionine. However, most changes in amino acid requirements do not lead to changes in the relative proportions of the different amino acids. There is therefore an ideal balance of dietary amino acids for poultry, and changes in amino acid requirements are normally expressed in relation to a balanced protein or ideal protein.

Fats and fatty acids

Because of the greater energy density of fat compared with carbohydrates and protein, poultry diets usually include fats to achieve the needed dietary energy concentration. Fat accounts for about 3 to no more than 5 percent of most practical diets. Other benefits of using fats include better dust control in feed mills and poultry houses, and improved palatability of diets. Poultry do not have a specific requirement for fats as a source of energy, but a requirement for linoleic acid has been demonstrated. Linoleic acid is the only essential fatty acid needed by poultry, and its deficiency has rarely been observed in birds fed practical diets. Linoleic acid's main effect in laying birds is on egg size.

Minerals

Minerals are needed for formation of the skeletal system, for general health, as components of general metabolic activity, and for maintenance of the body's acid-base balance. Calcium and phosphorus are the most abundant mineral elements in the body, and are classified as macro-minerals, along with sodium, potassium, chloride, sulphur and magnesium. Macro-minerals are elements required in the diet at concentrations of more than 100 mg/kg.

Calcium and phosphorus are necessary for the formation and maintenance of the skeletal structure and for good egg-shell quality. In general, 60 to 80 percent of total phosphorus present in plant-derived ingredients is in the form of phytate-phosphorus. Under normal dietary conditions, phytate phosphorus is poorly utilized by poultry owing to the lack of endogenous phytase in their digestive enzymes. It is generally assumed that about one-third of the phosphorus in plant feedstuffs is non-phytate and is biologically available to poultry, so the phosphorus requirement for poultry is expressed as non-phytate phosphorus, rather than total phosphorus. A ratio of 2:1 must be maintained between calcium and non-phytate phosphorus in growing birds' diets, to optimize the absorption of these two minerals. The ratio in laying birds' diets is 13:1, because of the very high requirement for calcium for good shell quality.

Dietary proportions of sodium (Na), potassium (K) and chloride (Cl) largely determine the acid-base balance in the body for maintaining the physiological pH. If a shift occurs towards acid or base conditions, the metabolic processes are altered to maintain the pH, with the likely result of depressed performance. The dietary electrolyte balance is described by the simple formula ($Na^+ + K^+ - Cl^-$) and expressed as mEq/kg diet. Prevention of electrolyte imbalance needs careful consideration, especially in hot climates. Under most conditions, a balance of about 250 mEq/kg of diet appears satisfactory for optimum growth. The overall balance among these three minerals, and their individual concentrations are important. To be effective, their dietary levels must each be within acceptable ranges, not deficient and not excessive. Birds exposed to heat stress consume more water, and are better able to withstand heat when the water contains electrolytes. The replacement of part of the supplemental dietary sodium chloride with sodium bicarbonate has proved useful under these conditions.

Trace elements, including copper, iodine, iron, manganese, selenium, zinc and cobalt, function as components of larger molecules and as co-factors of enzymes in various metabolic reactions. These are required in the diet in only very small amounts (Table 1). Practical poultry diets should be supplemented with these major and trace minerals, because typical cereal-based diets are deficient in them. Organic forms of some trace minerals are currently available, and are generally considered to have higher biological availability than inorganic forms.

Vitamins

Vitamins are classified as fat-soluble (vitamins A, D, E and K) and water-soluble (vitamin B complex and vitamin C). All vitamins, except for vitamin C, must be provided in the diet. Vitamin C is not generally classified as a dietary essential as it can be synthesized by the bird. However, under adverse circumstances such as heat stress, dietary supplementation of vitamin C may be beneficial. The metabolic roles of the vitamins are more complex than those of other nutrients. Vitamins are not simple body building units or energy sources, but are mediators of or participants in all biochemical pathways in the body.

Water

Water is the most important, but most neglected nutrient in poultry nutrition. Water has an impact on virtually every physiological function of the bird. A constant supply of water is important to: i) the digestion of feed; ii) the absorption of nutrients; iii) the excretion of waste products; and iv) the regulation of body temperature. Water constitutes about 80 percent of the body. Unlike other animals, poultry eat and drink all the time. If they are deprived of water for even a short time, production and growth are irreversibly affected. Water must therefore be made available at all times. Both feed intake and growth rate are highly correlated with water intake. Precise requirements for water are difficult to state, and are influenced by several factors, including ambient conditions, and the age and physiological status of the birds. Under most conditions, water intake is assumed to be twice the amount of feed intake. Drinking-water temperatures should be between 10 and 25 °C. Temperatures over 30 °C will reduce consumption.

The quality of water is equally important. Quality is often taken for granted, but poor water quality can lead to poor productivity and extensive economic losses. Water is an ideal medium for the distribution of contaminants, such as chemicals and minerals, and the proliferation of harmful microorganisms. Water quality for poultry can be a major issue in arid and semi-arid regions where water is scarce. In particular, underground water in these areas can have high levels of salt. Saline drinking-water containing less than 0.25 percent salt is tolerated by birds, but can cause sodium toxicity if water intake is restricted.

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Advances in poultry nutrition

***Velmurugu Ravindran**, Monogastric Research Centre, Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand*

Feed represents the greatest single expenditure associated with poultry production. Nutritional research in poultry has therefore centred on issues related to identifying barriers to effective digestion and utilization of nutrients, and on approaches for improving feed utilization. Poultry nutritionists have increasingly combined their expertise with that of specialists in other biological sciences, including immunology, microbiology, histology and molecular biology.

Although broilers and layers are highly efficient in converting feed to food products, they still excrete significant amounts of unutilized nutrients. For example, in their manure, broilers lose almost 30 percent of ingested dry matter, 25 percent of gross energy, 50 percent of nitrogen, and 55 percent of phosphorus intake. There is therefore considerable room for improving the efficiency of feed conversion to animal products. Much of the inefficiency results from the presence of undesirable components and the indigestibility of nutrients in the feed.

Recent advances in poultry nutrition have focussed on three main aspects: i) developing an understanding of nutrient metabolism and nutrient requirements; ii) determining the supply and availability of nutrients in feed ingredients; and iii) formulating least-cost diets that bring nutrient requirements and nutrient supply together effectively. The overall aim is *precision feeding* to lower costs and maximize economic efficiency. In the past, there was a tendency to overformulate diets when there was doubt about the availability of critical nutrients (especially amino acids and phosphorus) or when nutrient requirements were uncertain. This practice is no longer acceptable, not only because it is wasteful, but also because excess nutrients excreted in the manure are ultimately a source of pollution. Fine-tuning diets so that they more closely match the requirements of the birds, helps to optimize the efficiency of nutrient utilization. The major developments towards achieving the goal of precision feeding are discussed in the following sections.

DEFINING NUTRIENT REQUIREMENTS

Defining nutrient needs is challenging because they are influenced by several factors and are subject to constant change. The factors influencing nutrient requirements are of two main types: bird-related ones, such as genetics, sex, and type and stage of production; and external ones, such as thermal environment, stress and husbandry conditions. Precision in defining requirements requires accuracy in both areas. Great advances in the definition of nutrient requirements for various classes of poultry have been made possible largely by the increasing uniformity of genotypes, housing and husbandry practices throughout the poultry industry.

Defining requirements for the ten essential amino acids has been made easier by acceptance of the *ideal protein* concept. As for other nutrients, the requirements for amino acids are influenced by various factors, including genetics, sex, physiological status, environment and health status. However, most changes in amino acid requirements do not lead to changes in the relative proportion of the different amino acids. Thus actual changes in amino acid requirements can be expressed in relation to a balanced protein or ideal protein. The ideal protein concept uses lysine as the reference amino acid, and the requirements for other essential amino acids are set as percentages (or ratios) of the lysine requirement. Table 1 shows the ideal protein balances for meat chickens at different growth phases. The advantage of this system is that once the lysine requirements for a variety of conditions are determined, the needs for all other essential amino acids can be calculated. This approach has now become accepted practice for setting the amino acid specifications of feed formulations in the poultry industry.

DEFINING NUTRIENT COMPOSITION AND INGREDIENT QUALITY

Poultry producers are continually looking for opportunities that allow more flexibility in both the types and the levels of feed ingredients for use in feed formulations. Such opportunities are becoming increasingly frequent because of advances in nutrient analysis and feed evaluation techniques.

TABLE 1

Ideal amino acid ratios of meat chickens for three growth periods

Amino acid	1–21 days	22–42 days	43–56 days
Lysine[1]	100	100	100
Arginine	105	108	108
Histidine	35	35	35
Isoleucine	67	69	69
Leucine	109	109	109
Methionine + cysteine	72	72	72
Phenylalanine + tyrosine	105	105	105
Threonine	67	68.5	68.5
Tryptophan	16	17	17
Valine	77	80	80

[1] Recommended digestible lysine requirements for meat chickens of 1 to 21, 22 to 42 and 43 to 56 days are 1.070, 0.865 and 0.745 percent, respectively.

The principal role of feed ingredients is to provide the nutrients that the bird digests and utilizes for productive functions. Currently, considerable data are available on the ability of raw materials to supply these nutrients. However, a degree of variability is inherent to each raw material, and this places pressure on precise feed formulations. Data on variation (or matrices) are available for the main feed ingredients and are applied in feed formulation programmes to achieve better precision. A related development is the availability of *rapid tests*, such as near-infrared reflectance analysis, to predict gross nutrient composition and assess the variability in ingredient supplies on an ongoing basis.

It is recognized that not all the nutrients in ingredients are available for production purposes, and a portion of nutrients is excreted undigested or not utilized. As feed evaluation techniques develop, data have been accumulating on the availability of nutrients for poultry, especially of amino acids and phosphorus. For example, a recent development has been the wider use of *digestible amino acid* concentrations, rather than total amino acid concentrations, in feed formulations. The use of digestible amino acid content is particularly relevant in developing countries, where highly digestible conventional ingredients are not available and diet formulations may include ingredients of low digestibility. Formulating diets based on digestible amino acids makes it possible to increase the range of ingredients that can be used and the inclusion levels of alternative ingredients in poultry diets. This improves the precision of formulation, may lower feed costs, and ensures more predictable bird performance.

BETTER FEED FORMULATION

Once the nutritional needs are defined, the next step is to match these needs with combinations of ingredients and supplements. The object of formulation is to derive a balanced diet that provides appropriate quantities of biologically available nutrients. For commercial producers, a further object is to formulate a balanced diet at least cost. Given the range of possible feedstuffs and nutrients needed, a large number of arithmetical calculations are required to produce a least-cost diet. Over the years, feed formulation has evolved from a simple balancing of a few feedstuffs for a limited number of nutrients to a linear programming system that operates with the aid of computers. Systems using *stochastic non-linear programming* are now becoming popular, with commercially available formulation software. Variability in ingredient composition is non-linear, so stochastic programmes address this issue in the most cost-effective manner possible.

A related development is the use of *growth models* to simulate feed intake and production parameters under given husbandry conditions. Such models are effective tools for: i) comparing actual versus potential performance, which can indicate the extent of management or health problems in a flock; and ii) providing economic analysis of alternative feeding regimens. Several commercial growth models are available for predicting the production performance of both meat chickens and laying hens. However, because of the extreme complexity of biological responses, the models are only as good as the data used to establish them. There is a need for accurate and detailed information and data from a variety of production systems to enable the development of robust models that can provide accurate prediction of performance.

TABLE 2

Examples of biotechnological applications that are widely used in animal nutrition

Application	Aim(s) of the technology
1. New ingredients	To produce microbial proteins as new feed sources for animal feeding (e.g., single-cell protein, yeast protein)
2. Designer ingredients	To enhance nutrition (e.g., high-oil maize, high-methionine lupins) or reduce the level of anti-nutritive components in common feed ingredients (e.g., low-phytate maize)
3. Feed additives:	
a) Antimicrobials	To suppress the growth of harmful bacteria and promote the establishment of a desirable gut flora balance (e.g., antibiotics)
b) Crystalline amino acids	To increase the dietary supply of specific amino acids and improve the protein balance in diet formulations
c) Feed enzymes	To improve the availability of nutrients (energy, amino acids, phosphorus, etc.) in feed ingredients by reducing the negative effects of anti-nutritive components (e.g., microbial phytases acting on phytate, xylanases acting on arabinoxylans in wheat)
4. Gut ecosystem enhancers:	
a) Probiotics	To promote the establishment of a desirable gut ecosystem through the proliferation of beneficial species (e.g., direct-fed microbials)
b) Prebiotics	To exclude harmful organisms competitively, to promote the establishment of a desirable gut ecosystem (e.g., mannan oligosaccharides)

PRODUCTS OF BIOTECHNOLOGY IN POULTRY FEEDING

Progress in biotechnology during the past two decades has provided new opportunities for enhancing the productivity and efficiency of animals through improved nutrition. Biotechnologies have a vast range of applications in animal nutrition. Some of these are already in use (Table 2), while others are known to have potential but are not yet commercially applied because of technical limitations and public concerns (Table 3).

FEED PROCESSING

Today, after their ingredients have been mixed, most poultry feeds undergo some form of processing, which involves a wide range of thermal treatments including extrusion, expansion, conditioning and pelleting. Most of the feed used in the production of meat chickens is fed in pelleted or crumbled form, which enhances the economics of production by improving feed efficiency and growth performance. These improvements are attributed to decreased feed wastage, higher nutrient density, reduced selective feeding, decreased time and energy spent on eating, destruction of pathogenic organisms, and thermal modification of starch and protein. Introduction of pellet feeds is a notable feature in countries seeking to improve the production efficiency of the poultry sector.

PHASE FEEDING

The current recommendations for poultry list the nutrient requirements for only selected growth periods; the three periods of up to three weeks, three to six weeks, and six to eight weeks are con-

TABLE 3

Examples of biotechnological applications with future potential in animal nutrition

Application	Aim(s) of the technology
1. Modification of gut microbes	To modify genetically the microorganisms naturally present in the gut, to enhance their capacity for defined functions or to add new functions (e.g., rumen microbes to improve cellulose digestion)
2. Introduction of new gut microbes	To introduce new species or strains of micro-organisms into the gut
3. Bioactive peptides	Improved growth and efficiency (e.g., growth hormone-releasing peptides), improved gut function, immunomodulation, antibacterial properties
4. Antimicrobial replacers	Antimicrobial enzymes (e.g., lysozyme), to deliver specific antibodies via spray-dried plasma and egg products
5. Transgenesis	To modify nutrient metabolism and improve growth efficiency by transfer of genes

sidered for meat chickens. In practice, however, grow-out periods can range from four to ten weeks of age, depending on local market needs. Recognizing that changes in nutrient needs are more dynamic than these general recommendations, the commercial poultry industry is increasingly using phase-feeding systems to maximize performance and increase profit margins. Dietary protein and amino acid specifications are usually decreased in a progression of different feeds that satisfy changing requirements and economics. Typical feeding programmes over a five- to seven-week production cycle now include four to five feeds, such as pre-starter, starter, grower and finisher; or pre-starter, starter, grower, finisher and withdrawal. The withdrawal diets often fed during the last seven to ten days of growth involve removal of certain pharmaceutical additives and reduction of protein/amino acids. In recent years, they have also involved the reduction of certain vitamins and trace minerals, and energy.

WHOLE GRAIN FEEDING

Another recent development has been the feeding of whole grains (wheat or barley) along with a balanced concentrate feed. The benefits of whole grain feeding include better performance, reduced feed processing costs and improved flock health. These benefits appear to arise from a combination of two physiological actions: physical benefits of gizzard development and increased proventriculus secretions; and better matching of daily requirements through self-selection by the bird. The usual method of whole grain feeding is to blend 10 to 25 percent of the weight of the feed on top of the feed in delivery trucks or at the poultry house.

SUSTAINABLE POULTRY FEEDING

Not long ago, the main objective of formulating feeds was to supply nutrients (nutrient input). Today there is much public concern about what comes out of the bird (nutrient output). Animal agriculture, including the commercial poultry sector, is clearly releasing excess nutrients into the environment, and must assume responsibility for its impact on the environment, especially on water quality. Without question, the poultry industry must achieve the goal of sustainability, as environmental concerns have a major influence on its future growth and expansion. From a nutrition point of view, the most obvious strategy is to feed birds to match their requirements (precision feeding) and to improve the efficiency of birds' nutrient utilization, which will reduce the nutrient load in manure.

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Main ingredients used in poultry feed formulations

***Velmurugu Ravindran**, Monogastric Research Centre, Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand*

Feed represents the major cost of poultry production, constituting up to 70 percent of the total. Of total feed cost, about 95 percent is used to meet energy and protein requirements, about 3 to 4 percent for major mineral, trace mineral and vitamin requirements, and 1 to 2 percent for various feed additives. Poultry diets are formulated from a mixture of ingredients, including cereal grains, cereal by-products, fats, plant protein sources, animal by-products, vitamin and mineral supplements, crystalline amino acids and feed additives. These are assembled on a least-cost basis, taking into consideration their nutrient contents as well as their unit prices. Table 1 shows common ingredients used in poultry feed formulations in most parts of the world.

MAIN INGREDIENTS: AVAILABILITY ISSUES

Energy sources constitute the largest component of poultry diets, followed by plant protein sources and animal protein sources. Globally, maize (corn) is the most commonly used energy source, and soybean meal is a common plant protein source. However, other grains such as wheat and sorghum, and plant protein meals such as canola meal, peas and sunflower meal are also widely used in some countries. The main animal protein ingredients are fishmeal and meat meal. Almost all developing countries are net importers of these ingredients; the poultry feed industries in Africa and Asia depend on imports, which are a drain on their foreign exchange reserves. Quite often, the semi-commercial and commercial sectors in these countries are forced to limit their output of compounded feeds.

TABLE 1

Common ingredients used in typical poultry feed formulations

1. Energy sources:
   - cereals (mainly maize),[1] cereal by-products
   - animal fats and vegetable oils
2. Plant protein sources:[2] soybean meal
3. Animal protein sources: fishmeal, meat and bone meal
4. Mineral supplements:
   - calcium supplements: limestone, shell grit
   - calcium and phosphorus supplements: dicalcium phosphate, defluorinated rock phosphate, bone meal
   - trace minerals: trace mineral premixes
   - sodium sources: salt, sodium bicarbonate
5. Miscellaneous:
   - vitamin supplements: vitamin premixes
   - crystalline amino acids: methionine, lysine, threonine
   - non-nutritive feed additives: enzymes, antibiotics, etc.

[1] Wheat and sorghum are widely used in some parts of the world.

[2] Canola meal, peas and sunflower meal are also used in some parts of the world.

The diversion of grains, particularly maize, from the animal feed market to ethanol production is a major recent development that has caused severe grain supply problems in the world market, with dramatic price increases. With government policies to promote the use of biofuels, the global production of ethanol has rapidly increased in recent years, and further large increases are expected in the future. Despite record prices, the import demand for main ingredients in developing countries continues to increase to meet the feed demands of an expanding poultry sector, putting further pressure on prices. Paradoxically, the solution for the rocketing price of maize could come from the biofuel industry, through its major co-product – distillers' dried grains with solubles (DDGS) – which has been shown to be a good source of available amino acids and energy. Worldwide, feed millers are showing keen interest in DDGS because of its cost-effectiveness and ready availability. Good-quality DDGS is a potentially useful feed ingredient, containing about 25 percent protein and 10 percent fat, and rich mineral and vitamin resources. The amino acid availability in DDGS is similar to that in soybean meal. This may be the only raw material whose supply is assured and will increase in the future.

MAIN ENERGY SOURCE

The predominant feedgrain used in poultry feeds worldwide is maize. This is mainly because its energy source is starch, which is highly digestible for poultry. In addition, it is highly palatable, is a high-density source of readily available energy, and is free of anti-nutritional factors. The metabolizable energy value of maize is generally considered the standard with which other energy sources are compared.

In North America and Brazil, the feed industry has benefited from surplus maize, resulting from increased mechanization and the application of genetic and agronomic techniques to raise productivity. In the Asian and African regions, however, maize yield per hectare is low, and in most countries, production has never been sufficient to meet the needs of the growing human population. The net result is a continuing shortage of maize for feed use in these regions.

The other energy source that meets most of the same criteria as maize is low-tannin sorghum. Sorghum can be grown in low-rainfall areas and is a popular crop in hot, drought-prone regions. The high tannin content of many older sorghum varieties limits their use in poultry diets, but low-tannin varieties are now available and can be used in poultry diets without any limitation. The energy value of low-tannin sorghum is 90 to 95 percent that of maize.

MAIN PLANT PROTEIN SOURCE

After energy-yielding raw materials, protein supplements constitute the largest component of poultry diets. Plant protein sources supply the major portion of dietary protein (or nitrogen) requirements. The plant protein source traditionally used for feed manufacture is soybean meal, which is the preferred source for poultry feed.

Soybean meal contains 40 to 48 percent crude protein, depending on the amount of hulls removed and the oil extraction procedure. Relative to other oilseed meals, soybean protein has a good balance of essential amino acids, which can complement most cereal-based diets. The amino acid availability in soybean meal is higher than those for other oilseed meals. The metabolizable energy content is also substantially higher than in other oilseed meals.

Raw soybeans contain several anti-nutritional factors, including protease inhibitors, which can negatively affect protein digestion and bird performance. However, these inhibitors are destroyed by heat during the processing of soybean meal. Properly processed soybean meal is an excellent protein source for all classes of poultry, with no restrictions on its use.

Soybean production has increased substantially over the past two decades to meet the rising demands for oil for the human food market and meal for the animal feed market. The major producers of soybeans are the United States, Brazil and Argentina, which are also the major exporters. More than 50 percent of the current crop is now genetically modified (GM), mainly for herbicide tolerance, and there is an ongoing debate and campaign to reject GM ingredients from animal diets. If GM sources are not accepted in the market place, the potential for further nutritional quality enhancement and increased productivity will be limited.

MAIN ANIMAL PROTEIN SOURCES

With the notable exception of soybean meal, plant protein sources are generally nutritionally imbalanced in terms of essential amino acids, particularly lysine, the first limiting amino acid in cereals. Unless supplemented with animal protein sources and crystalline amino acids, plant-based diets may not meet the requirements for critical amino acids for egg and meat production. Owing to their high prices, animal protein ingredients are normally used to balance the amino acid contents of diets rather than as major sources of protein. In many countries, feed manufacturers ensure that animal protein ingredients do not fall below minimum levels in poultry diets, especially for young birds whose amino acid requirements are high. The requirements for essential amino acids are progressively reduced as the birds grow older, and it is possible to meet the needs of older birds with diets containing lower levels of animal protein and relatively higher levels of plant protein. Fishmeal and meat meal are the animal protein sources most widely used in poultry diets

FISHMEAL

Fishmeal is an exceptionally good source of high-quality protein, and its price usually reflects this. It also provides abundant amounts of minerals (calcium, phosphorus and trace minerals), B vitamins and essential fatty acids. The presence of unidentified growth factors is another feature of fishmeal. Feed formulations therefore seek to ensure minimum levels of fishmeal in diets.

Fishmeal consists essentially of dried, ground carcasses of fish. Good-quality fishmeal is brown, but the colour varies according to the type of fish used and the processing conditions. A very dark colour is indicative of overheating, which can destroy amino acids, reduce amino acid availability and substantially lower the protein quality.

Fishmeal is an important – sometimes the only – source of animal protein ingredients in most developing countries. It is either imported or locally produced. Local fishmeals typically contain between 40 and 50 percent crude protein, compared with more than 60 percent protein in imported fishmeals. Local fishmeals are generally of low quality owing to lack of control over raw fish quality, processing and storage conditions. They are often adulterated with cheap diluents, including poor-quality protein sources (dried poultry manure, oilseed meals), urea and non-nutritive diluents such as sand. Some fishmeals may be objectionable because of putrefaction, impurities or excessive salt content. Samples containing as much as 15 percent salt are not uncommon. This situation underlines the lack of quality control measures in most developing countries. As salt has laxative and growth depressing effects, the salt content of fishmeals should be carefully monitored; it should be less than 3 percent for best results, but legally may be up to 7 percent.

The correct quantity of fishmeal to include depends on the types of cereal and oilseed meals in the feed formulation. The cost of fishmeal is another important determinant. In general, average inclusion levels may be up to 8 percent for young birds, and less than 4 percent for older meat birds and layers. Higher levels must be avoided in finishing and laying diets, as they may lend a fishy taint to meat and eggs. Use of fishmeal can compensate, to an extent, where husbandry conditions are less than ideal.

Future expansion possibilities in fishmeal production are limited. Production does not seem to have increased over the past 20 years, and is unlikely to do so in the future, given the pressures on world fisheries. Fishmeal is included in the overall animal protein ban in Europe, and there is also an underlying concern about possible pollutant (e.g., dioxin) levels in fishmeal.

MEAT MEAL

Meat meal contains relatively high levels of protein, calcium and available phosphorus. Meat meal is the dry-rendered product from mammalian tissues, excluding hair, hooves, horns, hide trimmings, blood and stomach contents, except in such amounts as occur in good slaughterhouse practice. Meat meals are derived mainly from bones and associated tissues such as tendons, ligaments, some skeletal muscle, gastrointestinal tract, lungs and condemned livers. Variation in the proportions of these raw materials contributes to the large variations in meat meal quality. Depending on the proportion of bone to soft tissue used in the manufacture, the finished product is designated as meat meal (containing more than 55 percent crude protein and less than 4.4 percent phosphorus) or meat and bone meal (containing less than 55 percent crude protein and more than 4.4 percent phosphorus).

Collagen is the major protein in bone, connective tissue, cartilage and tendon, and contains no tryptophan. In poor-quality meat meals, 50 to 65 percent of total protein may be collagen. Increasing the level of bone in meat meal lowers the nutritive value, and the quality of its protein may vary greatly in terms of amino acid composition and digestibility. Protein quality is also affected by the temperature used to process the meat meal.

As a supplement to cereal-based diets, meat meal is of lower quality than fishmeal or soybean meal. Tryptophan is the first limiting amino acid in meat meal for poultry fed maize-based diets; lysine and methionine are also limiting. Normally, no more than 10 percent meat and bone meal is recommended for use in poultry diets, largely because phosphorus requirements are met at that level.

In recent years, feed manufacturers have to cope with increasing safety concerns, exemplified by the bovine spongiform encephalopathy (BSE) crisis, associated with the feeding of meat meal to ruminant animals. The use of meat meal in animal feed manufacture is now banned in some parts of the world, and the long-term future of this raw material seems uncertain.

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Feed supplements and additives

Velmurugu Ravindran*, Monogastric Research Centre, Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand*

The objective of feed formulation is to derive a balanced diet that will provide appropriate quantities of biologically available nutrients required by the bird. In addition to energy and protein, formulations contain supplements to provide minerals, vitamins and specific amino acids. These supplements must be added to all diets as they provide essential nutrients necessary for health and performance. Modern feed formulations also contain a diverse range of non-nutritive additives, which may not be essential but have an important bearing on performance and health. In many cases, the need for their inclusion is well understood: A major factor to be considered in selecting these additives is their efficacy. Feed supplements and additives are used in only small quantities, and it is particularly important that they are mixed carefully with the main ingredients so that they are evenly distributed.

NUTRITIONAL SUPPLEMENTS USED IN POULTRY FEED FORMULATIONS

Mineral supplements

Only part of birds' mineral requirements is provided by the natural feedstuffs in their diets. Mineral supplements must therefore be included in feed formulations.

Major minerals: Poultry require relatively large amounts of some minerals, such as calcium, phosphorus and sodium. Calcium and phosphorus are needed for normal growth and skeletal development, and poultry have unusually high requirements for calcium during the period of egg production, for the formation of strong egg shells. The calcium supplements commonly used in poultry feeding are limestone, crushed sea shells or sea-shell flour. Limestone powder can be included at no more than 3 percent, because higher levels will lower feed intake. It is therefore necessary to provide the extra calcium needed by high-producing layers as shell grit or limestone grit.

To meet the phosphorus needs of poultry, formulations must be supplemented with inorganic phosphorus sources. In diets containing fishmeal and meat and bone meal, supplementation with inorganic sources may not be necessary. The inorganic phosphates used in poultry diets are dicalcium phosphate, bone meal, rock phosphate, defluorinated phosphate and tricalcium phosphate, all of which supply both calcium and phosphorus. It is important that the inorganic phosphates are obtained from reliable sources, as contamination with fluorine can be a problem in some regions. Excess levels of fluorine in the phosphate source can adversely affect bird performance.

A recent development in phosphorus nutrition has been the availability of commercial phytase enzymes, which assist the bird's digestion and utilization of the phosphorus bound in phytic acid. This enzyme improves the availability of phosphorus from plant materials and reduces the need for inorganic phosphates in feed formulations. This enzyme is a non-nutritive additive.

Common salt is included in all diets as a source of sodium and an appetite stimulant. Salt is added in poultry diets at levels of 0.2 to 0.4 percent. Excessive salt increases water consumption and leads to wet excreta. The use of salt can be lowered or even omitted if more than 5 percent fishmeal is used in the diet.

Most formulations also contain 0.2 to 0.3 percent sodium bicarbonate (common baking soda); inclusion of this substance is particularly important in hot climates. When environmental temperatures are high, birds increase their respiration rate to increase the rate of evaporative cooling, thereby losing excessive amounts of carbon dioxide. This may be reflected in reduced growth rate and a decline in egg-shell quality, often seen in high-producing layers. Under these conditions, the replacement of part of the supplemental salt with sodium bicarbonate is recommended.

Trace minerals: These elements are required in the diet at concentrations in trace amounts, usually about 0.01 percent. Trace minerals (zinc, copper, iron, manganese, cobalt, selenium) are therefore usually added in the form of propriety premixes.

Vitamin supplements

All vitamins, except vitamin C, must be provided in the diet. Vitamins are required in only small amounts, and are usually provided in propriety vitamin premixes, which can be purchased from commercial suppliers. Although vitamin premixes represent only 0.05 percent of the diet, they can have a large effect on bird performance.

Crystalline amino acids

Pure forms of individual amino acids are now commercially available. Currently the limiting amino acids in poultry diets – methionine, lysine, threonine and tryptophan (in that order) – can be purchased at reasonable cost and included in poultry diets to balance dietary amino acid levels. Amino acid supplements now play a very important role in improving protein utilization in animal feeding.

TABLE 1

Non-nutritive feed additives commonly used in poultry feed formulations.

Additive	Examples	Reasons for use
Enzymes	Xylanases, ß-glucanases, phytase	To overcome the anti-nutritional effects of arabinoxylans (in wheat and triticale), ß-glucans (in barley) or phytate (in all plant feedstuffs); to improve the overall nutrient availability and feed value
Antibiotics[1]	Avilamycin,virginiamycin, zinc bacitracin, avoparcin, tylosin, spiramycin	To control gram-positive, harmful bacterial species in the gut; to improve production efficiency; as a prophylactic measure against necrotic enteritis
Coccidiostats	Monensin, salinomycin, narasin	To prevent and control the clinical symptoms of coccidiosis
Pigments	Xanthophyll (natural and synthetic)	To increase yolk colour in eggs and to improve the skin colour and appearance of carcasses
Antioxidants	Butylated hydroxy toluene (BHT), butylated hydroxy anisole (BHA), ethoxyquin	To prevent auto-oxidation of fats and oils in the diet
Antifungals		To control mould growth in feed; to bind and mitigate the negative effects of mycotoxins
Antibiotic replacers[2]		
i. Direct-fed microbials	Probiotics	To provide beneficial species such as *lactobacilli* and *streptococci*
ii. Prebiotics	Fructo oligosaccharides (FOS), mannan oligosaccharides (MOS)	To bind harmful bacteria
iii. Organic acids	Propionic acid, diformate	To lower gut pH and prevent the growth of harmful bacteria
iv. Botanicals	Herbs, spices, plant extracts, essential oils	To prevent the growth of harmful bacteria
v. Antimicrobial proteins/ peptides	Lysozyme, lactacin F, lactoferrin, α-lactalbumin	To prevent the growth of harmful bacteria

[1] The use of avoparcin, zinc bacitracin, spiramycin, virginiamycin and tylosin phosphate as animal feed additives was banned in the European Union in 1998.
[2] Envisaging a total ban on in-feed antibiotic use, a multitude of compounds (individually and in combination) are currently being tested.

NON-NUTRITIVE ADDITIVES USED IN POULTRY FEED FORMULATIONS

Poultry formulations also contain an array of substances known as "feed additives". These are non-nutritive substances usually added in amounts of less than 0.05 percent to maintain health status, uniformity and production efficiency in intensive production systems. These additives have now become vital components of practical diets. Table 1 presents a list of commonly used feed additives.

Two recent developments relating to feed additives deserve special mention. First, there is increased interest in the use of feed enzymes to improve the utilization of nutrients in raw materials and to reduce feed cost. Improvements in nutrient availability are achieved by one or more of the following mechanisms: i) degradation of specific bonds in ingredients not usually degraded by endogenous digestive enzymes; ii) degradation of anti-nutritive factors that lower the availability of nutrients; iii) increased accessibility of nutrients to endogenous digestive enzymes; and iv) supplementation of the enzyme capacity of young animals. Enzymes widely used in the poultry industry are the carbohydrases that cleave the viscous fibre components in cereals (Table 1) and phytases that target the phytic acid-complexes in plant ingredients. More recently, technically successful enzyme preparations for use in maize-soybean diets have become available. Future advances in feed enzyme technology will involve the development of enzymes that can be used to target the anti-nutritive factors in non-traditional feedstuffs and improve their feeding value.

The second development is the recent ban on the use of in-feed antibiotics in animal feeds in some countries. In other countries, the number of in-feed antibiotics available for use in poultry diets has been restricted. Antibiotics have been used in poultry diets for many years as protection against pathogens and sub-clinical diseases, and for the resulting improved growth. The withdrawal of this preventive measure has serious implications for the productivity of birds, encouraging considerable research effort into finding potential alternatives for antibiotics, some of which are listed in Table 1.

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Alternative feedstuffs for use in poultry feed formulations

Velmurugu Ravindran*, Monogastric Research Centre, Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand*

Global consumption of poultry products, especially poultry meat, has consistently increased over the years, and this trend is expected to continue. Much of the increase in global demand for poultry products will be in developing countries. Such growth in the poultry industry is having a profound effect on the demand for feed and raw materials. However, it is also becoming clear that the requirements for the four traditional feed ingredients – maize, soybean meal, fishmeal and meat meal – cannot be met, even according to optimistic forecasts. The gap between local supply and demand for these traditional ingredients is expected to widen over the coming decades, providing a compelling reason for exploring the usefulness of locally available, alternative feedstuffs in feed formulations.

A wide range of alternative feedstuffs are available for feeding in all three poultry production systems. The greatest potential for efficiently utilizing these feedstuffs will be in traditional family poultry systems (scavenging and backyard) and the semi-commercial system. In the semi-commercial system, only part of the feed requirement is purchased from commercial compounders, so there is opportunity for on-farm mixing or dilution of purchased feeds with locally available, alternative feedstuffs. In low-input family poultry systems, locally available, alternative feedstuffs can be used to supplement the scavenging feed base.

NON-TRADITIONAL FEEDSTUFFS – THE ISSUES

Alternative feedstuffs are often referred as "non-traditional feedstuffs" because they have not traditionally been used in animal feeding or are not normally used in commercial animal diets. However, it is difficult to draw a clear distinction between traditional and non-traditional feeds. Feedstuffs that may be classified as non-traditional in some regions, may actually be traditional and based on many years of usage in others. Some feedstuffs may have started as non-traditional, but are now being used increasingly in commercial diets. A good example is palm kernel meal, which is a non-traditional feedstuff in Western Africa, but an increasingly normal feedstuff for feed millers in Southeast Asia, especially in pullet and layer diets.

It is widely recognized that in developing African and Asian countries, existing feed resources in many circumstances are either unutilized and wasted or used inefficiently. Most of these alternative feedstuffs have obvious potential, but their use has been negligible owing to constraints imposed by nutritional, technical and socio-economic factors (Table 1). Three major criteria determine the regular use of a feedstuff in commercial diets: i) it must be available in economic quantities, even if its availability is seasonal; ii) the price must be competitive against the main feedstuffs; and iii) its nutritive value must be understood, including its nutrient content, existing variation and nutrient digestibility. In many developing countries, in may be difficult to assess the nutritive value of any feedstuff, owing to the lack or scarcity of appropriate research or analytical facilities. This is a major factor discouraging commercial feed mills from considering the use of alternative ingredients.

There has been keen interest in evaluating alternative feed resources over the years, and a proliferation of published data, especially from developing countries. Lists of alternative feedstuffs that seem to have the greatest potential as substitutes for maize, soybean meal and animal proteins are presented in Tables 2, 3 and 4, respectively. These lists are by no means exhaustive; this information note does not aim to review all the available literature on each individual ingredient, but rather to identify the general issues limiting their use and maximum inclusion levels in commercial poultry diets.

FUTURE PROSPECTS FOR ALTERNATIVE FEEDSTUFFS

The immediate prospects for the use of alternative feedstuffs listed in Tables 2, 3 and 4 will be in semi-commercial poultry units that employ some degree of on-farm feed mixing, and family poultry units. In these sectors, where the objective is economic

TABLE 1

Factors limiting the use of alternative feed ingredients in poultry feed formulations

Nutritional aspects - Variability (or lack of consistency) in nutrient quality - Limited information on the availability of nutrients - High fibre content - Presence of anti-nutritional factor(s) - Need for nutrient supplementation (added cost)
Technical aspects - Seasonal and unreliable supply - Bulkiness, physical characteristics - Need for de-hulling and/or processing (drying, detoxification) - Limited research and development facilities for determining nutrient composition and inclusion levels in poultry diets
Socio-economic aspects - Competition with use as human food - Poor prices relative to other arable crops (farmer) - Cost per unit of energy or limiting amino acids, relative to traditional feedstuffs (feed manufacturer) - Cost of processing

TABLE 2

Alternative energy sources that can replace maize in poultry diets

Feedstuff	Comments
Cereals	
Wheat	Can be used when cost-competitive Limitation: high non-starch polysaccharide contents result in intestinal digesta viscosity problems; can be used without restriction when exogenous carbohydrases are added
Sorghum	Limitation: tannins lower protein and energy digestibility; low-tannin sorghum can completely replace maize
Millets	Can replace 50–65% of maize, depending on millet type Limitations: high fibre contents, presence of tannins
Cereal milling co-products	
Rice bran/polishing	Limitations: high fibre, phytic acid, rancidity; good-quality material can be used at levels of 5–10% in broiler diets and up to 40% in layer diets
Wheat bran/pollard	Limitation: high fibre; can be used at levels less than 5% in broiler diets and up to 15% in layer diets
Roots and tubers	
Cassava root meal	High in starch, excellent energy source Limitations: low protein, powdery texture, needs detoxification to remove the cyanogenic glucosides; can be used at levels of 30–40% in nutritionally balanced, pelleted diets
Cassava peel meal	Limitations: high fibre, very high levels of cyanogenic glucosides, needs processing; carefully prepared meal may be used at 5% level
Sweet potato tuber meal	High in starch, good energy source Limitation: powdery texture; can be used at levels up to 50% in nutritionally balanced, pelleted diets
Taro	Limitations: poor palatability caused by calcium oxalate, needs processing; processed meal can be used at up to 10%
Fruits and fruit co-products	
Banana and plantain meal	Limitation: low palatability due to tannins in the peel; removal of peels improves nutritive value; inclusion must be limited to 10–20%
Breadfruit meal	Good energy source; can be included at up to 30%
Jack seed meal	Limitations: lectins in raw seeds, needs processing; processed meal can be included at up to 30%
Mango seed kernel meal	Limitation: high levels of tannins; processed meal can be used at levels of 5–10%
Date waste	Limitation: high sugar content; use must be restricted to 30% of the diet
Miscellaneous	
Sago meal	Limitation: powdery texture; can be included at up to 25%
Cane molasses	Limitations: high sugar content, wet litter problems; use must be limited to 15% of the diet
Animal fat	Tallow, lard and poultry fat; high-density energy sources that enable the use of low-energy feedstuffs in formulations; can be used at up to 5–8%
Distillers dried grains with solubles (DDGS)	High fat content (10%), good energy source; can be used at up to 25%

TABLE 3

Alternative protein sources that can replace soybean meal in poultry diets

Feedstuff	Comments
Oilseed meals[1]	
Cottonseed meal	Limitations: high fibre, presence of gossypol; low-gossypol meal can be used at levels of 10–15% in broiler diets; limit use in layer diets because of effects on internal quality of eggs
Canola meal	Limitation: glucosinolates; low-glucosinolate meals can be used at up to 30%
Groundnut meal	Limitations: tannins, aflatoxin; good-quality meal can be used at up to 15%
Sunflower meal	Limitation: high fibre Rich in methionine; can be used at up to 15%
Sesame meal	Limitation: high phytate content Good source of methionine; can be used at up to 15%
Palm kernel meal	Limitations: high fibre, poor texture, low palatability; good-quality meal can be used at levels of 5–10% in broiler diets and up to 30% in layer diets
Copra (coconut) meal	Limitations: low protein, mycotoxins; can be used at up to 20%
Rubber seed meal	Limitations: low protein, presence of cyanogenic glucosides, requires processing; can be used at up to 10%
Grain legumes[2]	
Lupins, field peas, chick peas, cowpeas, pigeon peas, faba beans, etc.	Limitations: presence of anti-nutrients, low in methionine; can be used at up to 20–30% when processed and supplemented with methionine; current cultivars contain low levels of anti-nutrients
Green meals	
Leaf meals, aquatic plant meals	Rich in minerals, moderate levels of protein Limitations: high fibre, high moisture content and requires drying; most green meals can be used at levels less than 5%; some, such as duckweed, can be included at higher levels
Distillery co-products	
DGGS	Good source of protein, amino acids and available energy Limitation: variable amino acid availability; good-quality meals can be used at up to 25%

[1] Compared with soybean meal, other oilseed meals have lower contents of available energy, protein and essential amino acids, and require supplementation with synthetic amino acids and energy sources. Suggested inclusion levels are for nutritionally balanced diets.

[2] A range of grain legumes are grown in developing countries. Only selected species are identified here. It must be noted that all raw legumes contain a number of anti-nutritive factors, but most of these can be eliminated by processing.

productivity rather than maximum biological productivity, alternative feedstuffs can make a useful contribution to poultry feeding.

Before the use of these feedstuffs can be considered in the modern commercial poultry sector, most – if not all – of the limitations identified in Tables 2, 3 and 4 must be resolved. A number of other possibilities are available for improving the feeding value and increasing the inclusion levels of many of these alternative feedstuffs: i) formulation of diets based on digestible amino acids, rather than total amino acids; ii) use of crystalline amino acids to balance amino acid specifications; and iii) supplementation with commercial exogenous enzymes to improve nutrient and energy

TABLE 4

Alternative animal protein sources for use in poultry diets

Feedstuff	Comments
Dried fish silage	A way of turning waste fish into quality animal protein supplement; can completely replace fishmeal Limitation: requires drying
Blood meal	High protein content Limitations: extremely deficient in isoleucine, poor palatability; can be included at no more than 5%
Hydrolysed feather meal	High protein content Limitations: deficient in several essential amino acids, low availability of amino acids; can be included at no more than 5%
Poultry by-product meal	Feeding value similar to that of meat meal; recommended inclusion level of 5%
Skimmed milk powder	Reject milk powder; good-quality protein; can be included at up to 5%
Novel sources: insects, fly larvae, earthworms, termites, bees, snails, etc.	Good protein sources; can replace 50% of fishmeal in formulations; useful supplements for family poultry Limitation: no commercial production and harvesting systems

availability. The effect of supplemental enzymes on alternative feedstuffs is twofold: first, they eliminate or reduce the action of anti-nutritive factors; and second, they increase digestibility and improve nutritive value

The greatest potential for using alternative feedstuffs is in the feeding of layers, irrespective of the production system. Owing to physiological differences, pullets and layers are more tolerant to high fibre, poor-quality feedstuffs and nutritional challenges than fast-growing meat birds are. Some of these feedstuffs can be included at high levels, but have negative effects on egg production. Rice bran and palm kernel meal are good examples of this tolerance; both can be used at maximum levels of only 10 percent in broiler diets, but may be safely incorporated into pullet and layer diets at levels of up to 30 percent.

SUPPLEMENTARY FEEDING STRATEGIES FOR FAMILY POULTRY

The scavenging area for family poultry is usually limited and often over-scavenged. The quantity and quality of the feed base for family poultry are also very variable, depending particularly on the season, but also on rainfall and agricultural activities. The supply of protein, minerals and vitamins is often high during the rainy season, owing to the abundance of insects and green materials, but becomes critical during the dry season. On the other hand, most of the materials available are deficient in energy throughout most of the year, because the feed base is generally high in fibre. Overall, feed consumed by family poultry can be considered deficient in all major nutrients – energy, protein, calcium and phosphorus. It is therefore recognized that scavenging alone will not provide enough feed to support the needs for growth or egg production, and that body weights and egg numbers can be markedly improved by the provision of supplementary feed. Small amounts of strategically administered supplements are likely to increase production and minimize mortality. Several of the alternative feedstuffs identified in this information note can play an important role as supplementary feeds.

Unlike the intensive poultry production system, the family poultry system lends itself well to the inclusion of locally available, alternative feedstuffs. Most of these feedstuffs are available only seasonally, in limited quantities and in specific locations, but can easily be accommodated within the family poultry system. Many of these materials are dusty in nature, and could be wasted if offered in dry form. To avoid wastage, these materials are therefore best offered as wet mash.

Energy supplements

The main feature of the traditional poultry system is that it does not directly compete with humans for the same food. However, where possible, it is advisable to offer small amounts of grains such as millets, maize and sorghum as energy supplements. Attention must therefore be paid to available cereal by-products. In most households and locations, several by-products from cereal milling are available for animal feeding, including bran, hulls and screenings. Despite their high fibre contents, these can be valuable sources of energy.

Small and damaged tubers and roots of cassava, sweet potatoes and yams, which are unfit for human consumption, are available in many areas and could be processed into a high-energy animal feed. The most practical method is to slice, sun-dry and pound or grind them into a meal. Cassava peels (which constitute 10 percent of the tuber weight) are not used for human consumption, and represent an economical feed for family poultry. However, they contain high levels of cyanide and must be processed to eliminate this toxic factor prior to feeding; simple sun-drying is adequate for this. Residues from the production of fermented cassava products can also be useful energy supplements.

A number of locally available fruit by-products can be used to provide energy. A good example is banana peels, which can be collected from local markets, sun-dried and milled into a meal. Proper drying is important to avoid spoilage and bacterial growth. A similar meal can be prepared from mango seed kernel, which has to be boiled prior to drying. On their own, both these meals have poor palatability and have to be offered in a mixture with other feedstuffs.

In areas where breweries or fruit processing operations are located, by-products may be collected and offered to poultry in wet form. These materials are good sources of supplemental energy.

Protein supplements

Green materials

Green materials are the cheapest sources of protein available to family poultry. A wide range of materials are available, including herbs, fodder leaves (e.g., leucaena, calliandra, sesbania), leaves from cultivated plants (e.g., cassava) and aquatic plants (e.g., azolla, water hyacinth, duckweed). These can be grown in small plots around the household. Where lagoons are available, the cultivation of aquatic plants should be promoted. The advantage of green materials is their high dry matter yields, which can be harvested and fed directly to poultry in fresh form. Not only are these materials good sources of protein, but they are also rich in pigments, vitamins and minerals.

Industrial by-products

By-products from local industries such as oil mills (palm kernel meal, sesame meal, coconut meal, rubber seed meal) and fibres (cotton, kapok) represent good sources of protein. Some of these materials are already used to supplement the feeding of family poultry.

Animal and fish by-products

In areas where there are fishing and meat processing operations, there is good potential for using offal for poultry feeding, in either fresh form or after processing. For example, the edible flesh of most types of fish represents only 40 percent of their total weight, leaving 60 percent for use as a protein feed resource. Scrap fish and fish wastes or residues (heads and offal) can be dried and processed into a meal, or be preserved as silage. The technique for making fish silage is simple, but the producer requires training.

Meals from insects

Insects can be used to produce cheaper proteins from non-food animals. Insects are part of the natural diet of poultry, and scavenging poultry consume a wide variety, including grasshoppers, crickets, termites, aphids, scale insects, beetles, caterpillars, pupa, flies, fleas, bees, wasps and ants. Insects are rich in protein, with reported protein contents ranging from 40 to 75 percent. These novel protein sources can be collected from surrounding areas. There is also opportunity for the production of insects using waste materials.

Insect larva: The biological digestion of animal wastes by the larval stage of flies (especially house and soldier flies), and the harvest and use of larvae and pupae is a cheap way of supplying high-protein materials to family poultry. Insect larva can be produced from kitchen and animal wastes. The materials are left to decompose in a protected area, where insects come and lay their eggs. Guidelines on the medium- to large-scale production of fly pupae using animal wastes describe how light is used to induce the migration of larvae out of the waste, through a screen and into a lower compartment, where they pupate and are harvested.

Termites: Termites are not only collected from nature, but can also be grown near the family unit and harvested. Termites have a unique ability to digest fibre, and the production of termites should be linked to the recycling of wood and paper wastes. A simple method of rearing termites on crop residues for family poultry supplementation is practised in some African countries. This involves the use of inverted clay pots containing termites and filled with moistened fibrous material. The pots must be protected against excessive heat and desiccation, and the termite larvae can be harvested after three to four weeks.

Meals from small animals

Earthworms: Earthworms are a natural food source for poultry kept under free-range systems and, live or dried, are highly palatable to poultry. Worm cultivation for fishing is common in many countries. Earthworms can also easily be produced and harvested for feeding family poultry, based on the biodegradation of animal manure. Techniques for the culture of earthworms (referred to as vermiculture) are well established and can be modified to suit small-scale production systems. Successful culture of earthworms requires: i) a food source; ii) adequate moisture (more than 50 percent water content); iii) adequate aeration; and iv) protection from excessive heat. A kilogram of earthworms consumes and digests 0.5 to 1.0 kg of waste a day. Because worms are top feeders, most of them will be found in the top 10 to 20 cm of the manure and can easily be harvested. Alternatively, the chickens can be let into the area to harvest the worms themselves. Under suitable growing conditions, up to 30 000 worms per square metre of surface area may be harvested.

Snails: The African giant snail is a major garden pest, which is particularly abundant during the wet season. The collection and use of snails as animal feed is therefore also of interest in the context of pest control. The bodies of snails contain hydrocyanic acid, presumably accumulated from the ingestion of cyanide-containing materials, but this toxic factor can be completely eliminated by cooking.

Mineral and vitamin supplements

Scavenging birds have far greater opportunity to balance their own micronutrient requirements. In the scavenging situation, minerals and vitamins are often provided from organic and non-organic materials pecked from the environment by the birds. Important sources of minerals and vitamins include snail shells, insects, fruits and fresh green materials.

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Animal feed safety

***Velmurugu Ravindran**, Monogastric Research Centre, Institute of Food, Nutrition and Human Health, Massey University, Palmerston North, New Zealand*

POTENTIAL HAZARDS ASSOCIATED WITH FEED

Feed safety and its regulation are of major international concern. Animal feeds are routinely subject to contamination from diverse sources, which may have serious consequences on the safety of foods of animal origin. Public concerns over food safety have heightened in recent years, because of problems such as bovine spongiform encephalopathy (BSE), melamine and dioxin contaminations, outbreaks of food-borne bacterial infections, and potential microbial resistance to antibiotics. Given the direct links between feed safety and the safety of foods of animal origin, it is essential that feed production and manufacture procedures meet stringent safety requirements.

Some sources of feed contamination are high priorities in all production systems and countries: i) mycotoxins (or fungal toxins); ii) pathogenic biological agents; and iii) various chemicals. These agents may contaminate feed at any stage of production up to the point of feeding, and can result in hazards in food of animal origin. Biological agents and chemicals normally enter the feed supply under specific conditions. Mycotoxins are more widespread, however, particularly in developing countries, because of improper agricultural, storage and processing practices. Not only do mycotoxins represent a food safety issue, but they can also have serious consequences on poultry performance, and so are discussed in some detail in this information note.

DISEASE-CAUSING BIOLOGICAL AGENTS

Poultry feed may be the source of human illness resulting from the consumption of poultry products. The agent of major concern in poultry feeds is salmonella, which is associated with food poisoning in humans. The principal manifestation of human salmonellosis is gastroenteritis. Salmonella is widely distributed in nature, and animal feed is only one of many sources for farm animals. Feedstuffs of animal origin are particularly frequently contaminated with salmonella.

Salmonella contamination can be avoided by sourcing and using salmonella-negative feedstuffs in diet formulation. Heat treatments of varying severity are commonly used to ensure the microbiological quality of animal feed.

CHEMICAL CONTAMINATION

A wide range of chemicals can enter the feed production system, intentionally or unintentionally. Potential hazards include veterinary drugs, agricultural chemicals (e.g., pesticides, fungicides), industrial chemicals (e.g., dioxin), heavy metals (e.g., mercury, lead, cadmium) and adulterants (e.g., melamine). These chemicals can accumulate in animal tissues, or are excreted in milk or incorporated in eggs, and cause health problems in humans.

Some veterinary drugs, such as antibiotics and coccidiostats, are routinely included in poultry feeds as additives. In meat-producing birds, the problem of drug residues in meat are overcome by providing a withdrawal diet containing no drugs for seven to ten days prior to slaughter. However, the possible development of microbial resistance due to the use of antimicrobials in animal diets has become a major public concern in recent years. As a result, the use of in-feed antibiotics is either banned or restricted in the poultry industries of developed countries.

Most other chemical contaminants enter feeds through plant materials, especially cereals and treated seeds. The levels of chemicals in plant materials are closely related to the levels of soil contaminants where they are grown. Similarly, animal fats used in formulations may contain high levels of lipid-soluble contaminants if they are produced from feed grown in polluted areas

MYCOTOXINS

The term "mycotoxin" refers to all toxins produced by various types of fungus when they grow on agricultural products before or after harvest or during transportation or storage. The most commonly affected feedstuffs are cereals, oilseeds and oilseed meals. These toxins have the capacity not only to impair bird performance, but also to affect humans through toxin residues that can be deposited in animal tissues. Many mycotoxins with different chemical structures and biological activities have been identified. Table 1 presents a list of major mycotoxins of economic importance in poultry feeds.

When environmental conditions are conducive to fungal growth, mycotoxin contamination of grains may start in the field, and can also take place during processing and storage of har-

TABLE 1

Origins of major mycotoxins found in common feedstuffs

Mycotoxin	Fungal species
Aflatoxins	*Aspergillus flavus; A. parasiticus*
Ochratoxins	*A. ochraceus; Penicillium viridicatum; P. cyclopium*
Trichothecenes	
- Deoxynivalenol	*Fusarium culmorum; F. graminearum*
- T-2 toxin	*F. sporotrichioides; F. poae*
Zearalenone	*F. culmorum; F. graminearum; F.pPoae*
Fumonisins	*F. moniliforme*

vested products. The moisture content of the harvested product and the ambient temperature are principal determinants of fungal contamination and mycotoxin production. Some fungi, such as *Fusarium* spp., normally infest grains before harvest; others, such as *Penicillium* spp., invade after harvest, while *Aspergillus* spp. can grow both before and after harvest. However, the presence of fungi does not necessarily indicate contamination with mycotoxins.

Different mycotoxins affect animals in different ways. Some are cancer-causing toxins (e.g., aflatoxin B_1, ochratoxin A, fumonisin B_1) and some are oestrogenic (zearalenones). Some affect the nervous system (fumonisin B_1), while others affect the kidneys (ochratoxins) or suppress the immune system (aflatoxin B_1, ochratoxin A, and T-2 toxin). Depending on the degree of contamination, these effects will eventually have negative impacts on performance. It is often difficult to diagnose the effects of a mycotoxin because they are not necessarily unique to a given mycotoxin, but may be shared by others or magnified by interactions with others. Many fungal species are also capable of producing several mycotoxins. Recent evidence has highlighted the co-contamination of feed samples with multiple mycotoxins, which has serious consequences for both feed safety and animal performance. The hazards induced by the simultaneous presence of several mycotoxins are not clearly understood.

In addition, depending on the degree of contamination, mycotoxins or their metabolites can be deposited in meat, visceral organs and eggs. Their concentration in animal products is considerably lower than the levels present in the feed consumed by the animals, and will not cause acute toxicity in humans, but residues of carcinogenic mycotoxins, such as aflatoxins and ochratoxin A, can affect human health. In most cases, however, the principal source of mycotoxins for humans is contaminated cereals and legumes rather than animal products.

Alfatoxins

Aspergilli, the fungi producing aflatoxins, proliferate under conditions of relatively high humidity and temperature, and are generally regarded as storage fungi. Aflatoxin contamination is therefore almost exclusively confined to hot climates. Aflatoxin levels in certain types of feeds (cereals and oilseed meals) are a major problem in tropical countries, and require careful monitoring and appropriate treatment. All poultry species are susceptible to aflatoxin, especially young ducks.

Ochratoxins

Ochratoxins are produced by one *Aspergillus* species and two *Penicillium* species. Both are storage species, but *Aspergillus* thrives in hot, humid conditions, whereas *Penicillium* fungi are essentially temperate. Ochratoxins are therefore problems in both tropical and temperate regions. Ochratoxin A and B are two forms that occur naturally as contaminants, with A being more ubiquitous and occurring predominantly in cereal grains and the tissues of animals fed with contaminated feedstuffs.

Fusarium mycotoxins

Fusarium fungi are "field moulds", as arable conditions (high moisture) favour their survival and growth. *Fusarium* fungi are ubiquitous, and cereal grains and animal feed are contaminated with *Fusarium* mycotoxins all over the world. The majority of *Fusarium* fungi have the ability to produce toxins. Of particular importance are the trichothecenes, zearalenone (ZEN) and the fumonisins. The trichothecenes include T-2 toxin and deoxynivalenol (DON; also known as vomitoxin). In addition, a given species can produce several different toxins, and grain crops are often contaminated by several *Fusarium* species at the same time. Thus, several toxins may be present simultaneously in contaminated feeds.

METHODS OF CONTROLLING OR DECONTAMINATING MYCOTOXINS

Mycotoxins are regularly found in feed ingredients such as maize, sorghum, barley, wheat, rice meal, cottonseed meal, groundnuts and other legumes. In general, mycotoxins are relatively stable compounds that are not destroyed by processing of feed, and may even be concentrated by screening. Feeds contaminated with mycotoxins in excess of established levels should not be fed to animals producing eggs or meat for human consumption.

It is not easy to prevent mycotoxins in the environment. Prevention of the contamination of agricultural commodities by fungi and their mycotoxins can be divided into the following three levels.

Primary prevention

The best pre- or post-harvest strategy to use in a particular year depends on the climatic conditions of that year. Unfortunately, avoiding weather that favours fungal infection is beyond human control. Nonetheless, understanding the environmental factors that promote infection, growth and toxin production is the first step in minimizing mycotoxins in feeds. Several practices may help to maintain conditions that are unfavourable for fungal growth: i) development of fungal-resistant crop varieties; ii) control of on-field infection with fungicides; iii) scheduling of harvests in the period suitable for the region; and iv) lowering the moisture content of the feedstuff after harvest and during storage.

Secondary prevention

This level of prevention is required when the fungi are already in the feedstuff. The fungi should be eliminated or their growth stopped to prevent further deterioration and mycotoxin contamination. The following measures may be useful: i) protecting stored products from conditions that favour continuing fungal growth; ii) using mould inhibitors (such as organic acids) against fungal growth; iii) storing commodity at low temperatures, where economically possible; iv) stopping the growth of infested fungi by re-drying the products; and v) removing contaminated material.

Tertiary prevention

When the product is heavily infested by toxic fungi, primary and secondary prevention are no longer feasible. If the mycotoxin levels are known, it may be possible to dilute the contaminated material and produce a final blended feed that contains less than the critical level of the specific mycotoxin. Such blending of feeds to reduce mycotoxin concentrations is officially permitted, with restrictions in several countries.

A number of additives are available for use in practical diets to remove or detoxify mycotoxins and reduce their negative effects on animals. These additives fall into two categories: mycotoxin binders, which bind and adsorb the mycotoxins and prevent their absorption in the gut; and mycotoxin deactivators, which deactivate specific mycotoxins. The effects of some mycotoxins (aflatoxin, ochratoxin and fumonisin) can be effectively reduced by the inclusion of appropriate adsorbent-type binders, while others (trichothecenes and zearaleone) can be removed only by deactivation. Common mycotoxin binders include hydrated sodium calcium aluminosilicate, esterified yeast-wall polysaccharides, and clays such as zeolites and bentonites. Different sorbents have differing affinities for specific mycotoxins. However, there is a risk that non-specific adsorbing agents may prevent the uptake of micronutrients in the gut. Some effective mycotoxin deactivators that are now available act by enzymatic degradation or biotransformation of mycotoxins.

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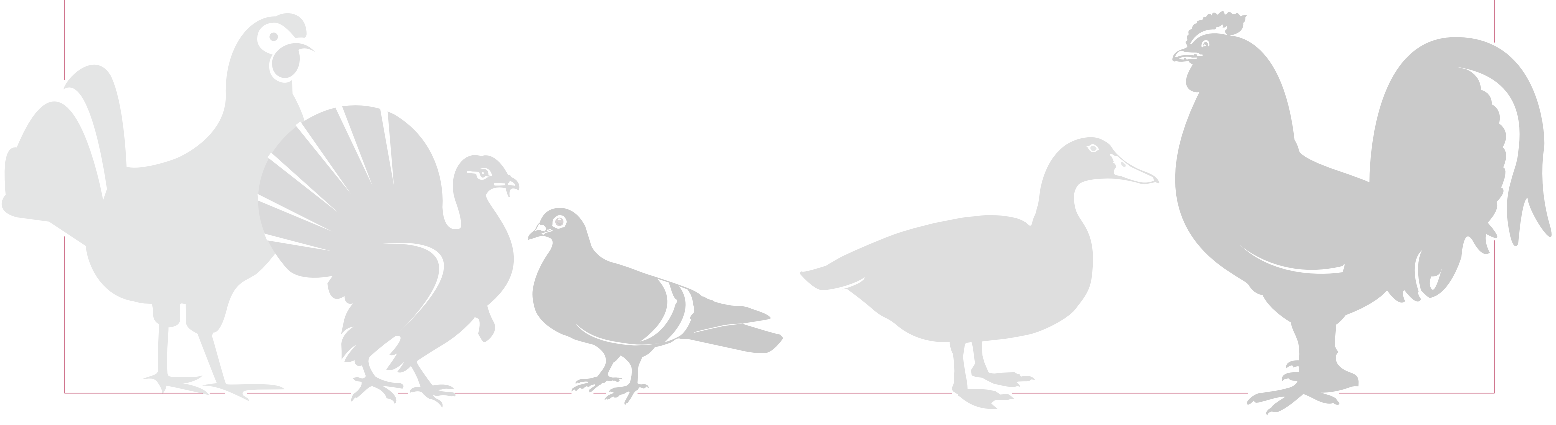
POULTRY DEVELOPMENT REVIEW

Poultry genetics and breeding in developing countries



Poultry genetics and breeding in developing countries

Robert Pym, *School of Veterinary Science, The University of Queensland, Gatton, 4343, Queensland, Australia*

DISTRIBUTION, MANAGEMENT AND PRODUCTIVITY OF POULTRY GENOTYPES

In most developing countries, there are two parallel poultry industries: one using high-performing commercial layer or broiler genotypes; and the other based on lower-performing, dual-purpose indigenous breeds.

The proportions in these two categories vary widely among countries, but in lower-income countries, indigenous stock comprises as much as 90 percent of the poultry population (Pym, Guerne Bleich and Hoffmann, 2006).

The critical distinction between the two forms of production relates to management: commercial stock are generally reared in confinement and housed in flocks ranging from 100 to 200 birds (small) to more than 10 000 birds (large). The birds are usually given compounded feeds, and the larger facilities are normally located close to urban areas. Indigenous stock are typically kept by families in rural and sometimes peri-urban areas, in small semi-scavenging flocks of ten to 30 birds, which are fed with household scraps and small amounts of other feed. Women and children are usually responsible for managing family flocks (Sonaiya, Branckaert and Gueye, 1999).

Performance differences between the genotypes are often very large.

Commercial layers developed from imported parent stock have the capacity to lay more than 300 eggs per year, while indigenous hens often lay only 40 to 60 eggs per year (Sørensen, in FAO, 2010). As well as the large difference in genetic potential to produce eggs, a very significant cause of the five- to eightfold difference in annual egg production is the time – 17 weeks – that a broody indigenous hen spends hatching a clutch of eggs and rearing the chicks to about seven weeks of age. During this time, she does not lay, which shortens the remaining time available for further egg production and means that she can produce only about 3.5 clutches per year.

Quantity and quality of feed is another significant factor in the disparity in annual egg production between the two genotypes. Commercial genotypes are normally provided with carefully compounded feeds, which include nutrients in the correct proportions for maximizing egg production. They are usually also fed *ad libitum*. The energy and protein intake of indigenous birds in scavenging flocks is determined by the scavenging feed resource base, and is usually quite limited, particularly in the dry season.

To maximize egg production, the capacity for broodiness has been bred out of commercial-strain layer hens. They are therefore incapable of natural reproduction, and their value in a village environment is thus quite limited.

The growth rate of indigenous genotype chickens is also generally much slower than that of commercial broilers. While broilers under typical confinement rearing may reach 2.0 kg live weight at five weeks of age, indigenous-breed male birds often weigh no more than 1.0 kg at 20 weeks (Sørensen, in FAO, 2010). This is a reflection of true genotype differences, but also of rearing environment, in which feed quantity and quality is the major factor.

Despite their lower productivity, in the village environment, the indigenous genotype birds have a number of advantages:

- The hens become broody, so can reproduce without the need for artificial incubation and brooding.
- They are agile and can run fast, fly and roost in trees, so can escape predators.
- They have been shown to be more resistant to bacterial and protozoan diseases and to parasitic infestations than commercial broilers or layers are.
- Their meat and eggs are generally preferred to those from commercial birds, not only by rural communities but also often by urban dwellers.

COMMERCIAL SELECTION FOR MEAT AND EGG PRODUCTION

The dramatic gains in poultry meat and egg production from individual birds in commercial flocks over the past 50 years are largely due to genetic selection in the nucleus breeding flocks of large global poultry breeding companies and the rapid transfer of these gains to the commercial cross-bred progeny.

This has been facilitated by high reproductive rates, short generation intervals, reduced environmental variation, large population sizes to minimize the detrimental effects of inbreeding, and the use of several differentially selected sire and dam lines.

To date, much of the improvement in performance has been derived from the application of quantitative genetic selection, with limited use of molecular technologies.

The large majority of commercial broilers and layers in developing countries have been produced from imported grandparent or parent stock originating from large global breeding companies. There are also a few smaller breeding operations that supply stock to regional markets.

Broilers

The continued annual productivity gains of commercial broiler flocks are a reflection of the complex and coordinated approach adopted by breeders to maximize performance. Breeders have selected for such traits as growth rate, breast meat yield, food utilization efficiency, skeletal quality, heart and lung function, and livability. This has had considerable positive effects on bird welfare, as well as on the environmental impact of production.

Over the past 30 years or so, genetic selection for growth rate, feed efficiency, yield and livability is estimated to have reduced the feed required to produce 1 tonne of chicken meat from 20 to 8.5 tonnes, a 2.4-fold reduction (McKay, 2008). ***This has had profound positive impacts on the environment and on the availability and cost of poultry meat to the human population.***

Breeders continue to pay attention to growth, feed efficiency, meat yield, skeletal quality, general robustness and disease resistance.

Layers

In commercial flocks, egg number, size, shell and internal quality, and layer livability, persistency of production and feed efficiency continue to improve, owing to ongoing selection for these and correlated traits.

Current average annual egg production is well in excess of 300 eggs per hen, and continues to increase by more than one egg/hen/year, while the annual feed requirement for producing 300 eggs is declining by about 200 g/hen. With some 6 billion layer hens worldwide, this translates into savings of more than 1 million tonnes of feed per year.

At present, layer breeding programmes focus on robustness and disease resistance, as reflected in significant improvements in livability and welfare. Considerable attention is also given to uniform size and colour of eggs and to freedom from shell and internal defects.

Both broiler and egg breeding programmes are now concentrating on molecular marker-assisted selection (genomics). This approach provides a means of identifying and selecting for or against the genes affecting production traits, particularly those that are difficult to measure, and for the genes affecting disease resistance.

GENETIC APPROACHES TO IMPROVED PERFORMANCE IN SUB-OPTIMAL CONDITIONS

The non-genetic factors mitigating against good performance from poultry in developing countries typically include:

- high temperatures;
- sub-optimal nutrition;
- increased disease challenge;
- sub-optimal housing and management conditions.

All genotypes are affected by these factors. Alongside efforts to improve the physical environment, possible genetic approaches include:

- selection in commercial genotypes for improved tolerance to prevailing conditions;
- cross-breeding between commercial and indigenous genotypes;
- introgression of genes from commercial genotypes, via backcrossing or cockerel exchange programmes;
- selection for improved performance in indigenous genotypes.

Selection in commercial genotypes

The genetic stock from which the large majority of commercial broilers and layers in developing countries are derived was selected for production under relatively ideal management conditions in temperate climates. Little if any emphasis has been given to tolerance to high temperatures or to sub-optimal management and feeding conditions.

High ambient temperature is probably the main factor limiting the performance of commercial broilers and layers in medium to large-scale production units in tropical developing countries. Other factors can be addressed at moderate cost by establishing appropriate management strategies, but the cost of facilities and the availability of a secure and reliable electricity supply make shed cooling problematic.

A relatively simple approach to improving heat tolerance in commercial stock, without having to develop separate full selection lines, is to incorporate single genes affecting feather cover into the parent lines of stock to be used in high-temperature regions. Reduced feather cover facilitates loss of body heat. Genes shown to be effective in conferring heat tolerance include naked neck *(Na),* scaleless *(sc)* and frizzle *(F)* (Cahaner *et al*., 2008). Commercial lines that express some of these genes are now available in some countries.

Irrespective of selection for heat tolerance, commercial broiler and layer genotypes require good management and feeding to realize their genetic potential for meat or egg production. They are not capable of good performance under semi-scavenging village conditions.

Several approaches have been used in efforts to incorporate the genes associated with superior egg and meat production in commercial strains into stock intended for use in less optimal environments. Such environments range from semi-scavenging village production systems, where virtually the only inputs are household scraps, through small-scale to medium-scale commercial operations, where birds are confinement-reared and fed with compounded diets, but are exposed to high ambient temperatures.

Cross-breeding

In many regions, local indigenous and commercial genotypes have been crossed in attempts to provide birds that are tolerant to local conditions while also capable of reasonable performance. In nearly all cross-breeding programmes, the cross-bred bird exhibits considerably better egg production and/or growth rate than the indigenous breed parent, but problems can be encountered with:

- loss of broodiness in hens, making them incapable of reproducing naturally;
- the need for maintaining separate parent lines/breeds and for the annual replacement of F1 cross-bred chicks;
- the need for additional inputs (particularly feed) to achieve the birds' genetic potential for production;
- a change in appearance and "type", which affects the birds' acceptability to farmers and the consumers of poultry eggs and meat;
- erosion of the genetic resource.

Introgression and cockerel exchange

Another strategy for improving the performance of local populations is through introgression of genetic material. This can be achieved though back-crossing or cockerel exchange programmes.

Experience has shown that for a back-crossing programme to be sustainable, increasing levels of supplementary feed and improved management and disease control are required as the frequency of exotic genes increases. Cockerel exchange programmes involve distributing cocks of improved breeds to smallholders. However, several reports have concluded that this type of improvement has not changed the basic populations, except for contributing to a larger variation in plumage colour (Besbes, 2008).

Selection within indigenous breeds

Selection for improved production within indigenous breeds or ecotypes is problematic for the following reasons:

- Effective selection depends on accurate recording of pedigree and performance.
- All birds should be subject to similar environmental variation.
- Egg production under cage confinement may be poorly correlated with reproductive performance under semi-scavenging conditions.
- The components of reproduction under semi-scavenging conditions are very complex, making selection under these conditions exceedingly difficult.

Despite considerable genetic variation in most indigenous breeds for egg and meat production, the complexity of the production system and of the desirable traits presents considerable obstacles to effective selection for improved performance. There are examples where performance has been improved through this approach, but they are few and the gains have been modest (Sørensen, in FAO, 2010).

GENETIC DIVERSITY AND CONSERVATION OF GENETIC RESOURCES

There is widespread concern in developing countries that as a result of replacement of low-producing breeds, urbanization, crossbreeding and the stamping out of flocks in response to outbreaks of disease, the world is losing valuable and irreplaceable poultry genetic material.

Concerns about a loss in genetic variability in commercial poultry strains have also been voiced following dramatic global reductions in the number of commercial poultry breeders and the number of populations under selection over the last 20 years (Arthur and Albers, 2003). ***A major concern is that the reduced genetic variability could place the industry in jeopardy in the event of a major disease outbreak involving new virus strains.***

The State of the World's Animal Genetic Resources, *published by FAO, found that of 2 000 avian breeds for which data were available, 30 percent were reported at risk, 35 percent not at risk, and the remainder were of unknown risk status* (Hoffmann, 2008).

In the past, genetic diversity was largely determined by phenotype. Recently, DNA analysis has provided an invaluable new technology for determining the relationships among individuals, breeds and ecotypes. Clustering methods using microsatellite markers have been effectively applied to assign individuals to their breed of origin, and to determine the degree of genetic diversity between populations.

Recent studies have shown a large range of within-breed or ecotype heterozygosities, of 28 percent for a fancy breed, 40 percent for white-egg layers, 45 to 50 percent for brown-egg layers, 50 to 63 percent for broilers, and 67 percent for a population of village chickens (Tixier-Boichard, Bordas and Rognon, 2008).

Studies in Africa have suggested that village chickens do not seem to exhibit a typical breed structure. While there is a high degree of between-bird variation in a village, differentiation between populations is observed only among those separated by large geographical distances. There is therefore considerable exchange of birds among adjacent villages. This suggests that many countries' claims to have a significant number of breeds or ecotypes of indigenous village-type chickens in a region may well be found by molecular measures to be based on a minimal degree of genetic diversity.

An integrated approach to breed characterization is required, and data on production systems, phenotypes and molecular markers should be combined to facilitate this. A comprehensive description of production environments is needed, to improve understanding of the comparative adaptive fitness of specific animal genetic resources.

The characterization of defence mechanisms against pathogens should be a priority, given the significance of the threats posed by epizootics and climate change. Field and on-station phenotypic characterization is therefore highly desirable.

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Contribution of indigenous genotypes to production and consumption of poultry meat and eggs

Robert Pym, *School of Veterinary Science, The University of Queensland, Gatton, 4343, Queensland, Australia*

LOCATION AND DISTRIBUTION OF INDIGENOUS BIRDS

Despite the lower productivity of indigenous poultry genotypes compared with that of commercial strains, indigenous genotypes still comprise a large proportion of the overall poultry population in many developing countries, frequently in excess of 80 percent. In rural villages in most countries, the majority of families have small flocks of poultry, mainly chickens but sometimes other species including ducks, turkeys and guinea fowls, which provide family needs for poultry meat and eggs. These birds are invariably indigenous genotypes, or cross-breeds with a significant indigenous genotype component.

Because chickens account for more than 90 percent of the total poultry population in most countries, and because only limited information on other poultry species is available, the following discussion focuses on chickens.

In most countries, flocks of indigenous breed birds are not found in significant numbers in urban or peri-urban areas, owing to the lack of scavenging opportunities. In some countries, there are restrictions on small-scale scavenging flocks in urban and peri-urban areas, because of the risk of disease transmission (particularly HPAI) to the human population and to commercial poultry flocks.

THE RETENTION OF INDIGENOUS POULTRY BREEDS

Their low productivity raises the question as to why indigenous chicken genotypes in rural regions have not been replaced by commercial genotypes. There are several reasons for this:

- Most indigenous genotypes still go broody, and can thus hatch their own eggs without recourse to artificial incubation and hatching, which are necessary for nearly all commercial genotypes.
- Most indigenous breed hens have strong mothering instincts and rear their young up to an age when they can fend for themselves under a scavenging management system.
- Most indigenous chicken genotypes are light-bodied, alert and can run fast and fly. They are thus more able to escape from predators than commercial genotypes, particularly meat chickens.
- In most countries, the meat and eggs from indigenous genotypes are generally preferred to those from commercial broilers and layers, not only by rural but also often by urban dwellers, who will pay a premium for these products.
- Indigenous genotypes have been shown to be more heat-tolerant and resistant to bacterial and protozoan diseases and parasitic infestations than commercial broilers or layers.
- Commercial broilers and layers perform far less well under scavenging than under commercial confinement rearing and feeding conditions. This poor performance and the cost of chicks make it uneconomic to rear commercial broilers under scavenging conditions.
- Although most regions have significant numbers of sector 3 small-scale commercial confinement rearing and feeding operations with broilers or layers, the cost and risk associated with setting up and operating such enterprises are prohibitive for most poor rural families.

The performance of indigenous genotypes improves under commercial confinement rearing and feeding conditions, but generally not to an extent that makes production economically viable, mainly owing to the cost of compounded feed. However, if the premium paid for eggs and meat is sufficiently high, this form of management in medium-sized units can be justified. This is to some extent self-limiting, because if the market is flooded with indigenous meat and eggs, the premium paid for them will fall.

CONTRIBUTION TO DOMESTIC PRODUCTION AND CONSUMPTION OF CHICKEN MEAT AND EGGS

The poor productivity of indigenous birds means that their total contribution to poultry meat and egg production and consumption is considerably lower than their numerical contribution to the overall poultry population. However, because of their large numbers, their estimated contribution to meat consumption can be quite high in many countries (Pym, Guerne Bleich and Hoffmann, 2006).

Based on published reports of flock structures, productivity and egg management in several countries, a study to estimate indigenous chickens' contribution to the overall consumption of chicken meat and eggs found that in countries where indigenous birds comprised about 80 percent of the total chicken population, adult indigenous breed hens accounted for about 20 percent of the total chicken population The study assumed that broilers and layers each made up about 10 percent of the standing population, that layers were replaced annually, and that there were four batches of broilers per year.

The study then estimated indigenous chickens' contribution to egg and meat consumption, based on:

- average egg production of between 40 and 60 eggs/hen/year from 3.5 clutches per bird;
- the preference in most communities for hatching the eggs to produce chicks, rather than eating the eggs;

- a generally high hatching rate of approximately 80 percent;
- a high chick mortality rate, with between 60 and 70 percent of chicks dying in the first seven weeks of life, meaning that an average of only one or two chickens are eaten per hatch of eggs.

The indigenous breeds' contribution to egg consumption was found to be low, at about 10 percent, while that to meat consumption was much higher, at about 50 percent.

Although these estimates are imprecise, in the absence of other published figures they provide a reasonable basis for comparisons of the production and consumption of indigenous and commercial genotypes. As countries develop and their populations become more urbanized, the proportions of meat and egg consumption from commercial genotypes increase. In rural regions, however, there are strong arguments for retaining indigenous genotypes in small family scavenging flocks.

The productivity and profitability of small-scale family poultry production are critically linked to bird mortality rates, particularly among young chicks. These are normally very high owing to predation, disease, malnutrition and climate exposure. Mortality rates have been shown to reduce dramatically when chicks are reared in confinement with the hen, are creep-fed for the first couple of weeks after hatching, and are vaccinated against Newcastle disease (Alders and Pym, 2008). Adopting these procedures will minimize losses and ensure that indigenous poultry genotypes continue to be important in rural communities for many years to come.

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Commercial selection for meat and egg production

Robert Pym, *School of Veterinary Science, The University of Queensland, Gatton, 4343, Queensland, Australia*

Breeding for meat and egg production is an exceedingly complex process involving effective and accurate selection for numerous traits in the sire and dam lines to ensure that the final cross-bred commercial bird possesses all the required attributes. As a consequence, breeding programmes are very costly.

A large population with significant numbers of active and reserve sire and dam lines is required to permit the full exploitation of genetic variation in the component traits and to reduce the effects of inbreeding. This makes it difficult for smaller breeding operations to compete effectively with large global breeding companies, although smaller breeding companies are viable suppliers to niche markets in some areas.

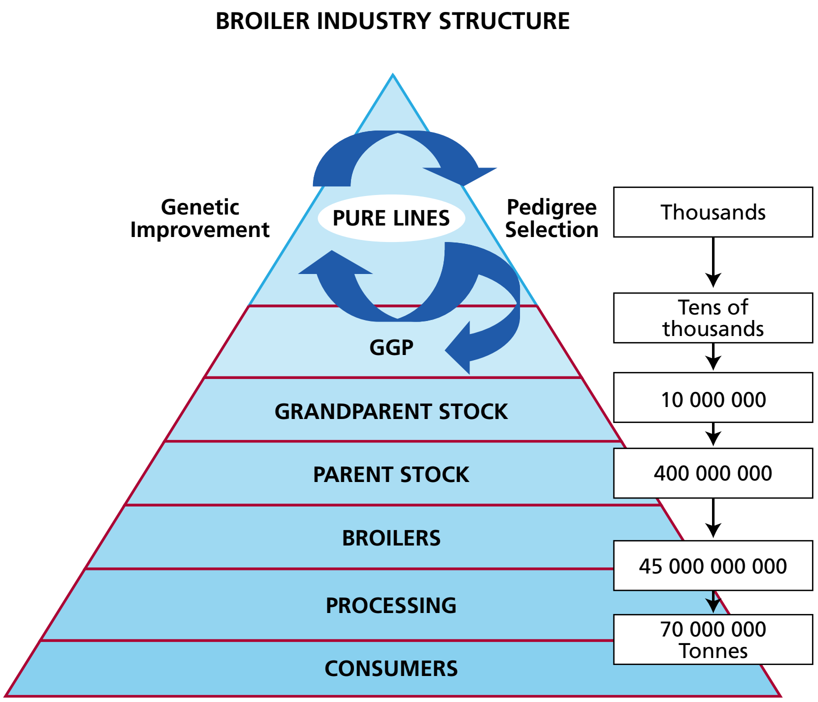
BROILER BREEDING PROGRAMMES

In commercial broiler breeding programmes, selection addresses the following areas:

- *Feed utilization efficiency:* As feed accounts for about 70 percent of production costs, the efficiency with which birds convert feed to body weight is an important trait for direct selection. To enable the selection of birds from the same conditions as their progeny are expected to perform in, some breeding companies have started to replace single-bird cage selection with selection of individual birds from group floor housing, using transponders on the birds and feeding stations to record food consumption.
- *Breast meat yield:* Because of the relatively high price of breast meat in developed countries, considerable efforts have been directed towards improving this trait. Approaches include sib selection based on conformation and, more recently, indirect measurement technologies involving real-time ultrasound, magnetic resonance imaging, computer-assisted tomography and echography.
- *Ascites:* Breeding for rapid growth and high breast meat yield resulted in an inadequacy in the cardio-pulmonary system's capacity to oxygenate the increased blood flow associated with the increased muscle mass. This led to a significant increase in ascites in broiler flocks during the 1990s, particularly during winter. Prior to this, ascites was normally encountered only un-

FIGURE 1

Numbers of birds and generations involved in the transmission of selection response from nucleus lines in commercial broiler breeding programmes to the commercial broiler progeny



Source: McKay, 2008.

der cold, high-altitude conditions. Selection based on oximetry and plasma levels of the cardiac-derived troponin-T enzyme was demonstrated to be effective in reducing susceptibility to ascites, and this procedure has been adopted by commercial broiler breeders. Levels of ascites in the field are now greatly decreased, even at high altitudes.

- *Skeletal abnormalities:* The very rapid growth rate of broiler chickens puts an enormous strain on their immature cartilaginous skeletons, resulting in high incidence of leg and skeletal abnormalities. Selection based on gait, morphology and X-ray imaging has done much to reduce the expression of conditions such as *tibial dyschondroplasia, spondylolisthesis* and *valgus* and *varus deformation* in most commercial strains of broilers, but skeletal abnormalities continue to be a major focus in most breeding programmes.

To permit the transmission of genetic improvement from the nucleus breeding populations (where all selection takes place) to the billions of cross-bred commercial broilers, significant multiplication through grandparent and parent populations is needed, as shown in Figure 1. The time lag between selection in the nucleus lines and gains in the commercial broiler is typically about four years.

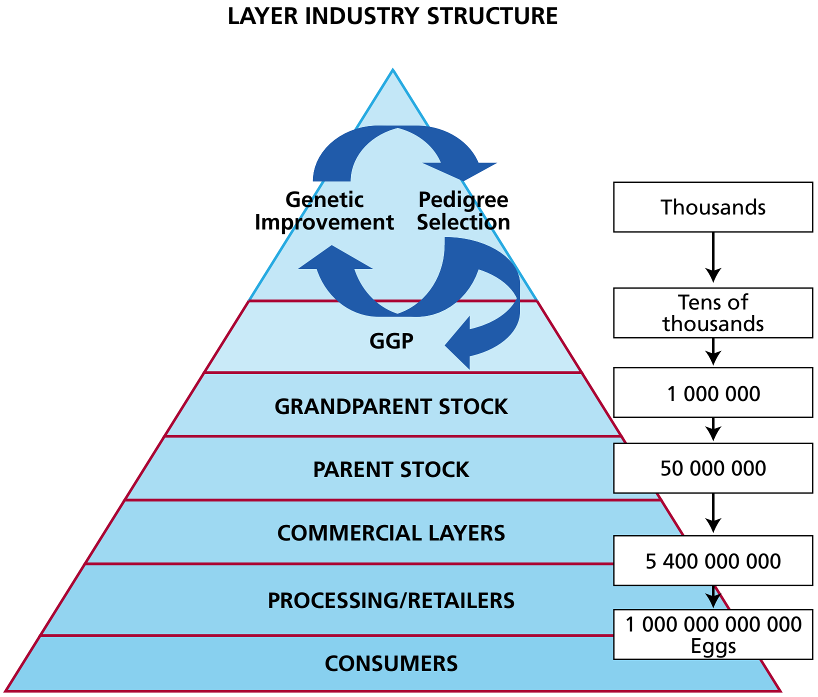
LAYER BREEDING PROGRAMMES

In commercial layer breeding programmes, selection addresses the following areas:

- *Egg production and size:* Genetic improvement in egg production and size is challenged by the highly canalized nature of the trait as determined by diurnal photoperiodic constraints; negative genetic correlations between egg production and early egg size; variation in the rate of increase in egg size with age; and the need to predict persistence of lay in birds selected for breeding before the third phase of production. High-capacity computers and sophisticated statistical packages involving Best Linear Unbiased Prediction (BLUP) procedures have been used to predict persistence in the laying performance of birds in current flocks, allowing selection to take place earlier and the maintenance of a relatively short generation interval.
- *Egg quality:* Shell quality is defined in terms of strength, colour, shape and texture; the first three have moderate to high heritabilities, so respond readily to selection. Shell colour is determined almost exclusively by genotype, and selection is typically based on measurement using reflectance spectophotometry. There are cultural preferences for eggs of different colours. Shell strength is a critical factor affecting profitability. Breeders have selected for improved shell strength by measuring shell thickness, specific gravity (of fresh eggs), shell deformation, and other indirect and direct parameters. Shell texture and shape aberrations and blood and meat spot inclusions are selected against by culling birds producing these eggs. Albumen quality has been improved by selecting for increased albumen height measured using a Haugh unit micrometer.
- *Selection in barn and free-range environments:* Effective selection for egg numbers and quality was not feasible in the past, when birds were housed under group pen conditions in barns, or free-range. Recently, technologies have been developed for attaching transponders to the birds and the nest box, with sensors that allow egg production to be recorded and eggs to be traced back to the hen that produced them, for quality measurement.

FIGURE 2

Numbers of birds and generations involved in the transmission of selection response from nucleus lines in commercial layer breeding programmes to the commercial layer progeny



Source: McKay, 2008.

The transmission of genetic improvement from the nucleus breeding populations (where all selection takes place) to the many millions of cross-bred layers involves significant multiplication through grandparent and parent populations, as shown in Figure 2.

RECENT EMPHASES IN COMMERCIAL BROILER AND LAYER BREEDING PROGRAMMES

Genomics: The sequencing of the chicken genome and the genetic variation map for chickens, developed in 2004, have had a profound impact on commercial broiler and layer breeding programmes. There are now some 3.3 million identified single nucleotide polymorphisms (SNPs) in the chicken genome, which provide large numbers of potential markers for quantitative trait loci (QTL) mapping and associated studies, allowing more accurate selection for multiple traits.

Genomics will not replace traditional selection methods, but will allow more accurate selection decisions to be made, and breeding companies have recently made considerable investments in bioinformatics. The greatest impact of this will be on difficult-to-measure traits such as disease resistance and sex-limited traits, and those with low heritability. Large international poultry breeding companies have recently committed to a combined initiative to evaluate and implement genome-wide selection in their respective breeding programmes.

Transgenics: There are three approaches to producing transgenic chickens: i) using viral vectors to introduce foreign DNA into the genome; ii) direct injection of DNA into the newly fertilized zygote; and iii) using a cell-based approach to make modifications to the genome. Of these, the last approach, using primordial germ cells, appears the most promising for successful targeted changes to the genome.

Although transgenic technologies open up exciting possibilities for poultry breeding, their application is impeded by consumers' reluctance to accept eggs and meat from transgenic commercial poultry.

Selection for disease resistance: Breeding for disease resistance can be effective through direct selection for resistance and immunity parameters by measuring the response of relatives. However, the use of molecular markers is preferred, to avoid the expensive and labour-intensive tests involved in defining resistance in the live bird. A huge global research programme is under way to identify the molecular basis of disease resistance to the wide array of viral, bacterial, protozoan and fungal diseases affecting poultry.

However, in spite of the enormous global effort involved, the molecular approach to disease resistance in poultry flocks has so far had only a modest impact. Two areas where relatively good response has been obtained are selection for resistance to Marek's disease, based on the Major Histocompatibility Complex (MHC) haplotypes, and selection for resistance to avian leukosis virus, based on receptor differences in the identified genes. Combined molecular and traditional sib-selection approaches have yielded significant improvements in general robustness in a number of commercial meat and egg strains.

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Genetic approaches to improved performance in sub-optimal conditions

Robert Pym, *School of Veterinary Science, The University of Queensland, Gatton, 4343, Queensland, Australia*

SELECTION IN COMMERCIAL LINES OF POULTRY

When producing poultry stock for developing countries, large global breeding companies tend to promote the strains that are used in developed countries, most of which have temperate climates, claiming that these strains are suitable for all environments. However, most of these strains have been selected for increased productivity and general robustness under relatively good management and nutrition conditions, generally without significant temperature stress. If they prove to be tolerant to sub-optimal conditions it is usually owing more to chance than to directed selection. To maximize performance, the companies often promote improved management standards and practices in the target countries.

Given the very wide range of nutritional factors that affect performance, large companies have not attempted to breed birds with tolerance to specific nutritional deficiencies, but a case could be made for selecting birds for increased tolerance to heat stress (Cahaner, 2008). Heat stress has a marked impact on performance, particularly the growth of broilers, owing to their high metabolic heat output. High temperatures are a feature of most developing countries, and maintaining reasonable house temperatures is either too costly or simply not possible, owing to a limited or lacking power supply and other factors. As a result of this susceptibility to heat stress in broiler strains, it is standard practice in many tropical developing countries to market the birds at an early age and low weight, before heat stress becomes a major problem.

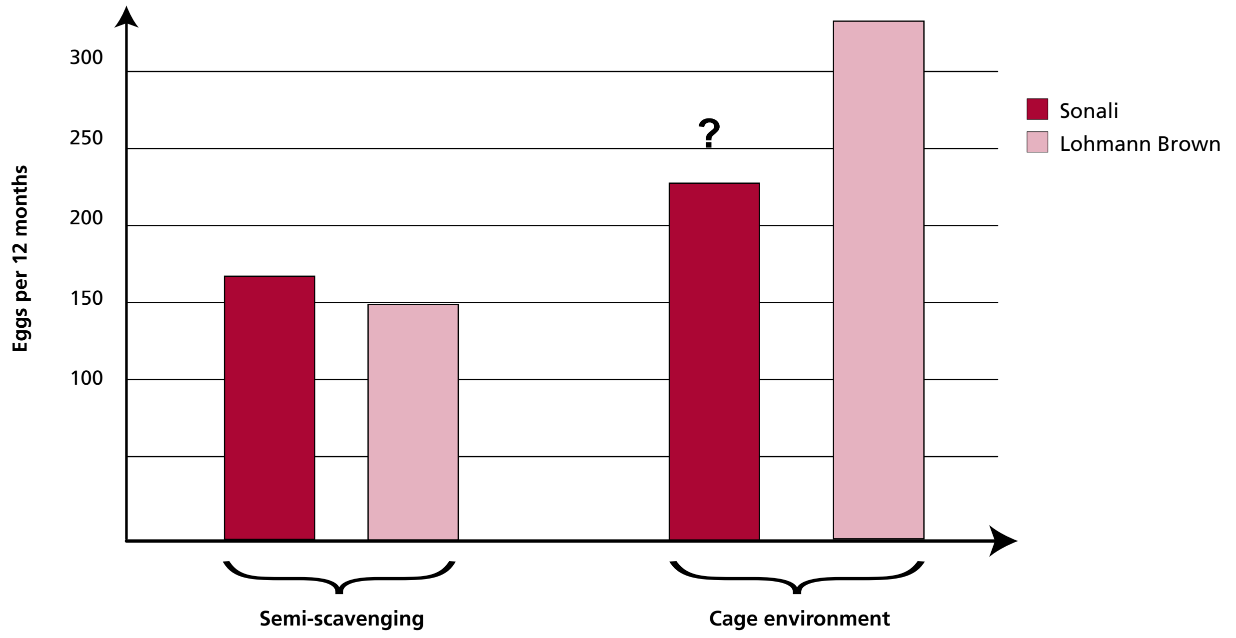
GENOTYPE-ENVIRONMENT INTERACTION

Studies have demonstrated genotype-environment interactions by measuring the growth or egg laying performance of different strains when subjected either to good management, high-input conditions or to harsh, low-input conditions (Besbes, 2008). Nutrient intake is typically one of the major differences between the two conditions. In almost all the cases studied, commercial stock performed considerably better than indigenous stock under good conditions, but only marginally better, or the same, under low-input, harsh conditions (Tadelle, Alemu and Peters, 2000; Singh *et al.*, 2004).

An example of this is the comparison of egg laying performance between Lohmann Brown and Sonali hens under optimal (German Random Sample Test) and semi-scavenging conditions

FIGURE 1

Effects of breed and environment interactions on egg production



Source: Sørensen, 1999.

(Sørensen, 1999). The Sonali hens are F1 crosses between Rhode Island Red males and Fayoumi hens. Figure 1 shows the relative performances of the two strains in the two environments. The Lohmann Brown produced 303 eggs in 12 months under the optimal conditions of the German Random Sample Test, but only 140 eggs under semi-scavenging conditions, where the Sonali produced 156. The Sonali was not tested under the German Random Sample Test, but its production was estimated at slightly more than 200 eggs (Sørensen, personal communication).

There is therefore a persuasive argument for applying genetics to produce stock that perform well under the less than optimal conditions prevailing in many developing countries. First, however, any improved management conditions that have been demonstrated to result in improved performance and that are cost-effective and sustainable should be applied, particularly those that improve the survival rate of young birds (confinement early rearing with the hen, with supplemental feeding and vaccinations), the supplemental feeding of growing and older stock with locally available feedstuffs, and ongoing disease prevention measures.

BREEDING FOR PERFORMANCE UNDER SUB-OPTIMAL CONDITIONS

Given the complex processes and inputs involved in genetic improvement, there is little point in attempting to improve the performance of a breed with inherently low production potential. Selection of the breed(s) to use is therefore critical, and involves a good understanding of each breed's specific attributes and a clear definition of the breeding goals.

Small-scale, semi-scavenging operations require dual-purpose birds that produce both eggs and meat. The opportunities for selecting for improved egg production are limited by the hen's hatching each clutch of eggs and rearing the chicks to about six or seven weeks of age before recommencing lay. The production system is complex, and emphasis on one component could have negative repercussions on another. Two obvious requirements are for broodiness and mothering ability. Some breeds/ecotypes are renowned as good layers and mothers, and are thus suitable candidate breeds, at least as the hens in any proposed cross-breeding programme. It is rather more difficult to apply effective selection at the individual bird level because of possible marked differences in the impacts of nutritional and disease factors on individual birds' performances. Nonetheless, there is a good case for culling poor-performing hens, although there is often limited opportunity to exert any selection pressure in smallholder situations, where all surviving hens are needed to maintain flock size.

The greater interest in meat than egg consumption in many developing countries justifies an emphasis on growth rate and body conformation, in all stock in single-breed operations, and in males in cross-breeding programmes. This should be balanced against the available feed resources. If the latter are limited, heavy body weight may be a disadvantage, as the bird may obtain sufficient nutrients to meet only maintenance requirements, with nothing left for growth.

In small-scale commercial operations involving confinement rearing and supplementary feeding, there is a persuasive argument for using commercial improved breeds/strains of broilers or layers. However, their suitability depends on the level and quality of feeding and the birds' likely exposure to extreme climatic conditions. Where feeding is sub-optimal and commercial diets are either not available or considered too expensive, there is a case for using local or other genotypes. One important factor is the relative prices paid for the meat and eggs produced by the different genotypes. Where a significant premium is paid for meat and eggs from indigenous breeds, the confinement rearing and feeding of these birds can be justified, in spite of their considerably lower productivity.

For all small-scale production systems in tropical developing countries, tolerance to high temperature is a key requisite in the birds. One of the most effective ways of improving heat tolerance is through the incorporation of single genes that reduce or modify feathering, such as those for naked neck *(Na)*, frizzle *(F)* and scaleless *(Sc)*, as well as the autosomal and sex-linked dwarfism genes, which reduce body size (Cahaner *et al.*, 2008). These genes are segregating in some indigenous populations, as there is natural selection for heat tolerance as an important component of reproductive fitness. There is also a good case for incorporating these genes into existing commercial lines, as the inputs and time required for this are minimal compared with those required to develop a high-producing, heat-tolerant line from a base population (Cahaner, 2008).

BREEDING APPROACHES

Cross-breeding

Genetic improvement can be achieved through cross-breeding, with or without genetic selection in the parent lines; through upgrading by repeated back-crossing to a superior parent breed; or through within-line selection. The cross-breeding approach normally involves a two-way cross between an improved exotic and a local breed, with the aim of combining the better production capacity of the former with the latter's adaptability to harsh environments. This system also maximizes the expression of heterosis, or hybrid vigour, in the cross, normally reflected in improved fitness characteristics.

Examples of this approach are the Bangladesh and Indian cross-breeding programmes, which are described in some detail by Sørensen (FAO, 2010). Briefly, the Bangladesh programme is based on crosses between Rhode Island Red (RIR) males and Fayoumi females to produce the F1 Sonali cross-bred. RIR is a United States breed that has been used by many commercial breeding companies globally as the base population for their brown-egg lines; Fayoumi is an Egyptian breed with reasonable egg production under difficult environments, and is particularly known for its genetic resistance to disease. The cross-bred Sonali fowl has proved to be the highest-yielding and most profitable breed combination in several comparisons under semi-scavenging conditions in Bangladesh (Rahman *et al.*, 1997).

The Indian programme is based on crossing Aseel breed males with CARI Red hens to produce cross-bred CARI Nirbheek hens. The native breed Aseel is well adapted to tropical conditions and is known for its high majestic gate and dogged fighting qualities, which make it capable of protecting itself against predators; the female CARI Red has been selected for improved egg production capacity under tropical conditions. In the field, CARI Nirbheek hens receiving about 30 g of supplementary feed per day were able to produce 163 eggs a year, with a survival rate of 90 to 95 percent (Singh *et al.*, 2004).

Upgrading through back-crossing

Poultry genetic improvement programmes through repeated back-crossing of female offspring with the superior-performing male parent breed, or through cockerel exchange programmes in which males of improved breeds are distributed to smallholders, have not been particularly successful. In both cases it is necessary to retain separate populations of parent birds, and the progeny often lose the capacity for broodiness, so cannot hatch or rear their young. This is a major shortcoming given the purpose for which the birds are being produced. In addition, the survival of improved breed males is often threatened by their lack of adaptation to the environment and its dangers. Not the least of these dangers is the attractiveness of these birds to other farmers, resulting in frequent thefts for breeding or eating. These limitations also apply to cross-breeding programmes.

Within-line selection

Within-line selection for increased growth or egg production involves complex procedures that have to be undertaken at a central breeding station (Besbes, 2008). The need for a sufficiently large population, pedigree recording, accurate measurement of individual performance and the capacity to minimize environmental variation makes it impossible for individual farmers to run an effective selection programme. Even when the necessary resources are available at a central breeding station, response is generally slow, and the logistics for distributing selected stock to farmers pose considerable difficulties. Economies of scale are very relevant, as evidenced by the dramatic reduction in the number of poultry breeding companies globally over the past 20 years.

There is certainly need for stock with the capacity to perform well under the less than optimal environments typically encountered in developing countries. The link between performance and nutritional and other management inputs means that any genetic improvement in performance capability must be matched by increased inputs. Genetic improvement through cross-breeding or back-crossing undoubtedly results in improved egg and/or meat production (provided it is accompanied by increased nutritional and other management inputs), but account should be taken of:

- the increased complexity of running several different lines;
- the birds' probable loss of broodiness and capacity to rear their young;
- the impact that it may have on farmers' interest in the chickens and on consumers' interest in their meat and their eggs.

Although within-line selection avoids most of these problems, to be effective, it needs to be conducted at a central breeding station, and to be well organized and funded. The choice of breed(s) for the base population is critical to the success of the enterprise.

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Genetic diversity and conservation of genetic resources

Robert Pym, *School of Veterinary Science, The University of Queensland, Gatton, 4343, Queensland, Australia*

BREED DEVELOPMENT AND GENETIC DIVERSITY

Globally, there is enormous genetic diversity within most poultry species resulting from:

- the activities of poultry fanciers and breeders around the world over many years;
- the prodigious numbers of small semi-scavenging flocks kept by subsistence farmers in developing countries;
- commercial breeders' efforts to produce high-performing meat and egg production lines of birds.

Many of the breeds developed over hundreds of years were selected for morphological and appearance characteristics as much as for production purposes. This is demonstrated by the huge numbers of chicken breeds and ecotypes found globally.

The principal features of poultry that permit rapid increases in the numbers of breeds and ecotypes in all countries are their very high reproductive rates and short generation intervals. Paradoxically, it is this capacity that now threatens the survival of many earlier-developed breeds. The need for high production efficiency, combined with the complexity and cost of running effective breeding programmes has resulted in commercially selected lines of broilers and layers replacing several of the breeds previously kept for productive purposes; over the past 20 years, there have also been dramatic reductions in the numbers of commercial breeding companies and genetic lines.

In any discussion of genetic diversity, "breeds" are essentially cultural concepts rather than physical entities. This is because breed standards have long been defined by phenotype, which may or may not involve significant differences in genotype. It is only recently that molecular tools capable of defining the degree of genetic diversity between different breeds have been developed. It is therefore necessary to adopt a broad definition of breed, until the term has been defined by a more objective measure.

Poultry breeds can be categorized into several different groupings according to present and past usage. Russell (1998) differentiates poultry breeds as: industrial or commercial lines; breeds used in traditional agriculture, historical breeds including old landraces; game breeds used primarily for cockfighting; ornamental breeds or those used mainly for exhibition; and experimental lines. Within these breeds there are many feather colour and comb variations (Simianer and Weigend, 2007), suggesting that a huge degree of genetic diversity is available, and posing questions regarding how best to allocate the limited resources for conserving this wide diversity as effectively as possible.

BREED CATEGORIES AND RISK STATUS

There is currently considerable concern regarding the number of poultry breeds that are either extinct or at risk of extinction. This information has been obtained from the *State of the World's Animal Genetic Resources* (FAO, 2007b), the first ever assessment of domestic animal diversity. The assessment process included updating the Domestic Animal Diversity Information System (DAD-IS) global databank, which now contains breed-related information on 16 avian species, with 3 505 country breed populations and about 2 000 breeds. Chicken breeds make up the vast majority (63 percent) of total avian breeds, followed by ducks (11 percent), geese (9 percent) and turkeys (5 percent); indigenous or local breeds make up most of the world's poultry genetic diversity. Breeds have been categorized according to whether they occur in one country (local), several countries in the same region (regional transboundary), or several regions (international transboundary). The proportions of each of these categories vary considerably from region to region (see Hoffmann, 2008 for details).

As noted by Hoffmann (2008), population data are frequently missing, which makes risk assessment extremely difficult. The absence of data is a result of the difficulties with monitoring small livestock and the general low importance that most governments attribute to poultry, despite their important roles for food security, rural livelihoods and gender equity. For 36 percent of reported avian breeds, the risk status is unknown; 35 percent are reported as not at risk, and 30 percent as at risk. Of 2 000 reported avian breeds, 9 percent – mainly chickens (83 percent) – were reported as extinct (FAO, 2007b). Most of these extinct breeds were from Europe (Figure 1).

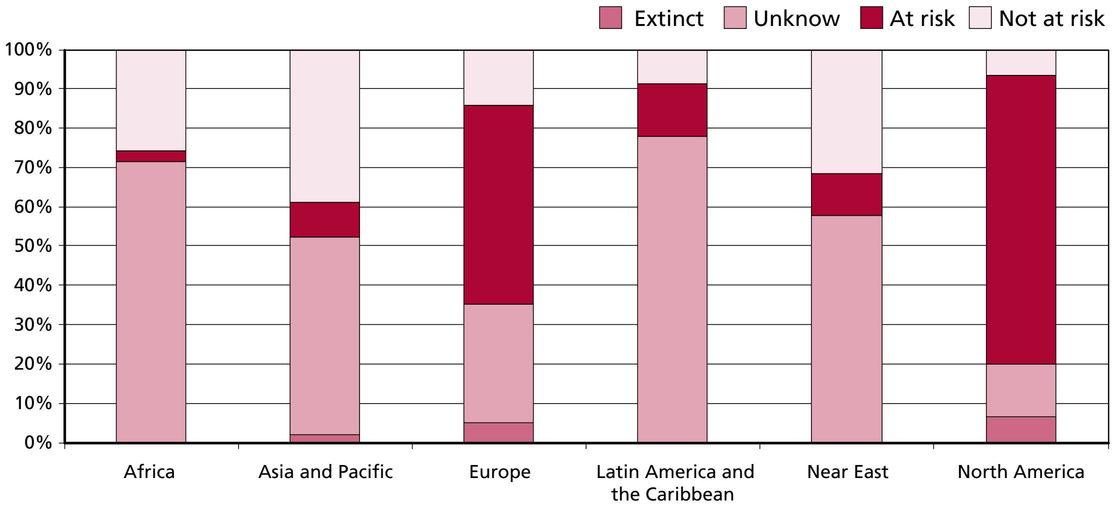
The regions with the highest proportions of avian breeds classified as *at risk* are North America, with 73 percent of total avian breeds, and Europe and the Caucasus, with 51 percent. Among the different avian species, the proportions of breeds at risk are 36 percent for chickens and turkeys, 31 percent for geese, and 25 percent for ducks.

CONSERVATION OF POULTRY GENETIC RESOURCES

Indigenous poultry breeds' importance for subsistence farmers in many developing countries, combined with many consumers' preference for their eggs and meat, suggests that these genetic resources are not under immediate threat. However, gradual erosion of the genetic integrity of the stock, through cross-breeding and upgrading programmes, is cause for concern. In addition, the actual genetic variation between so-called different breeds of indigenous birds in neighbouring regions has sometimes been shown to be minimal, owing to long-term exchanges of breeding

FIGURE 1

Risk status of local and regional chicken breeds, by region



Source: DAD-IS.

stock among villages. Substantial genetic diversity among village chicken populations is observed only in populations separated by wide geographical distances (Tixier-Boichard, Bordas and Rognon, 2008).

Poultry fanciers in developed countries play a vital role in the retention of genetically diverse populations of poultry species. The high reproductive rate and short generation interval of most species mean that viable breeding populations can be maintained at reasonable cost. Most "pure breeders" are motivated by the pleasure that the stock and the breeding enterprise bring them, but they are without doubt a largely untapped and vital source of avian genetic resources and diversity. These breeders and the smallholder poultry farmers in developing countries provide important means for the *in vivo* conservation of poultry genetic resources.

Recently, poultry genetic resources have suffered significant losses due to the termination of commercial lines associated with breeding company take-overs and the global consolidation of commercial poultry breeding operations. There have also been significant losses of experimental lines, most of which are generated at research institutions; it is becoming increasingly difficult to find the funds necessary for retention of these lines.

As well as *in vivo* conservation, genetic material is also conserved *in vitro*, mainly through cryo-preservation of semen. Under this approach, repeated back-crossing is required to re-establish a breed, which may take up to seven generations. In addition, the original genome of the lost breed can never be fully restored through this approach, owing to the loss of mitochondrial DNA. Although cryo-conserved embryos allow the complete re-establishment of a breed, this is not possible for avian species at present. Cryo-conservation of isolated embryonic cells, primordial germ cells or blastoderm cells may be an option in the future, but is currently too costly for genetic conservation programmes (Hoffmann, 2008).

CONSERVATION PROGRAMMES

From the FAO database, it is estimated that about 25 percent of chicken breeds are included in conservation programmes, but there is no information about the nature or efficiency of these programmes. According to country reports to FAO, only 15 percent of countries (half of them developing countries) have poultry conservation programmes (*in vivo and in vitro*), covering 63 percent of local breeds and 11 percent of national populations of transboundary breeds. The Global Databank shows that 195 poultry breeds (of which 77 percent are chickens, 9 percent ducks, 9 percent geese and 3 percent turkeys) have conservation programmes, but some of these data are out of date. Hoffmann (2008) provides details of country-specific programmes that may not be recorded in the Global Databank.

MEASURING GENETIC DIVERSITY

Recently, there has been a major shift from the differentiation of poultry breeds according to morphological and feather colouring characteristics, to differentiation based on measurements at the molecular level. The use of molecular markers can provide quantified criteria for assessing genetic diversity, either within or between populations. However, although they can be used to study relatedness between populations, provide information on past history of populations, detect introgressions and contribute to the genetic definition of a breed's entity, molecular markers do *not* provide information on phenotypes and special adaptive traits.

Appropriate sampling is critical to the molecular characterization of a breed for comparative purposes; a minimum of between 30 and 50 individuals is required. Determination of the chicken genome in 2004 (Hillier *et al.*, 2004) has facilitated the use of molecular markers for breed/ecotype characterization. Although genome knowledge is less complete for other poultry species, linkage maps are available for ducks, quails and turkeys, and reference to the chicken genome is generally an efficient approach for studying gene order and gene structure. The availability of molecular markers is therefore not a limiting factor in most poultry species. Highly polymorphic microsatellite markers are preferred because they provide much information for a limited number of loci; most studies use between 20 and 30 markers. Molecular tools for studying genetic diversity using single nucleotide polymorphisms are likely to be developed further.

GENETIC DIVERSITY WITHIN BREEDS AND POPULATIONS

As reported by Tixier-Boichard, Bordas and Rognon (2008), studies using microsatellite markers have shown large variations in heterozygosity, ranging from 28 percent for a fancy breed to 67 percent for a village population, but the average value (of about 50 percent) is rather lower than that observed in domestic mammals. The highest levels of within-population diversity were found in wild ancestor species, unselected local populations, a few standardized breeds kept in large populations, and some commercial broiler lines. A range of values were obtained for European fancy breeds, reflecting the variability of population history within this type of population. Expected values for heterozygosity range from 50 to 63 percent for broilers and 45 to 50 percent for brown-egg layers, to about 40 percent for white-egg layers, which exhibit the lowest levels of all commercial lines. These studies suggest that there is a significant reservoir of genetic diversity within local breeds of chickens.

MONITORING OF GENETIC POPULATIONS

The *Global Plan of Action for Animal Genetic Resources* (FAO, 2007a) identifies the need for country-based strategies to ensure that inventory and monitoring activities can be linked to and coordinated with action plans such as agricultural censuses or livestock population surveys. Monitoring requires the regular checking of population status and the evaluation of trends in the size and structure of breeds/populations, their geographical distribution, risk status and genetic diversity. Because of their important contribution to poultry meat consumption in rural regions of developing countries, it is highly desirable that local breed chicken populations are monitored. Such monitoring will contribute to the planning of national development policies in these countries.

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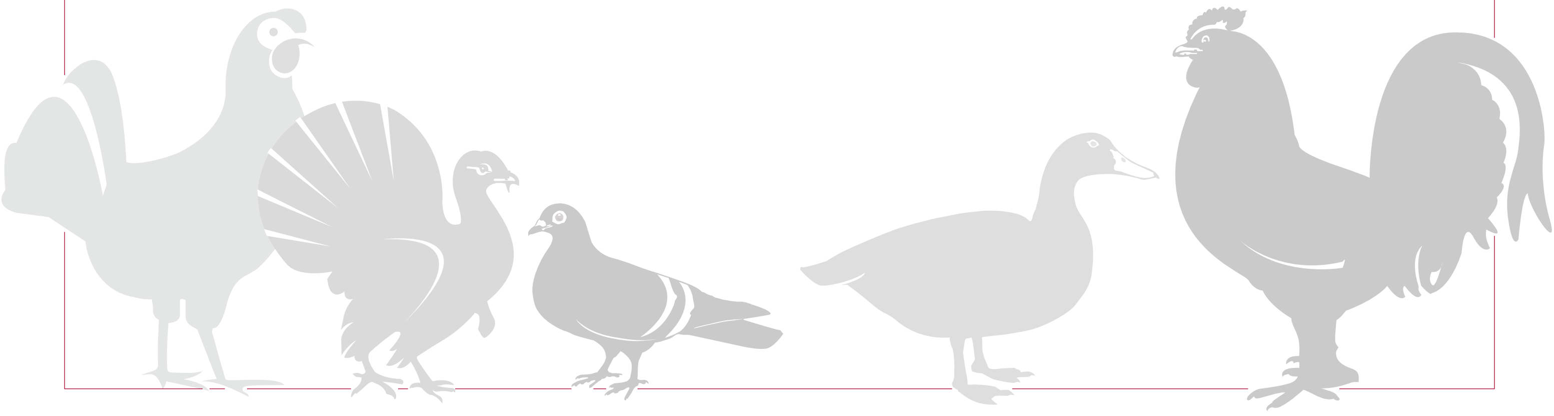
Poultry health and disease control in developing countries



Poultry health and disease control in developing countries

Trevor J. Bagust, *Department of Avian Medicine, Faculty of Veterinary Science, University of Melbourne, Australia*

INTRODUCTION

In the last half century, significant increases in the productivity of modern poultry stocks have been achieved for both the meat and the egg production sectors of the global poultry industry. Synergies have resulted from advances made in all the major activities of poultry management and housing, nutrition and ration formulation, applying poultry genetics knowledge in commercial breeding programmes and better diagnosis and control of avian diseases. Of all these core elements, poultry health and disease can be the least predictable.

Although poultry diseases from nutritional and metabolic causes can be of concern, the emphasis in this information note is on controlling diseases that are caused by infectious agents, which can exert damaging – and sometimes immediate – negative effects on the profitability of commercial operations. The development of an intensive poultry industry in many of the countries discussed here depends on the growth in number and size of small and medium-sized commercial poultry operations. The emphasis in this review is therefore primarily on optimizing poultry health for this scale of operations. Because of the importance of small-scale village-based production units in many developing countries, however, the poultry health implications for and from such flocks are also included.

POULTRY DISEASES: PATHOGENS AND THEIR COSTS TO PRODUCTION SYSTEMS

- *Pathogens are* disease-causing microorganisms, and include various bacteria, viruses and protozoa.
- *A specific pathogen* is a microbe that is able to cause a specific disease following inoculation of a susceptible host chicken with a purified culture. For example, avian health research has shown that ILT virus is the sole cause of the poultry respiratory disease syndrome recognized in the field as infectious laryngotracheitis (ILT), while the bacterium *Pasteurella multocida* is the specific cause of another respiratory disease known as subacute fowl cholera.
- "Although the relative importance of poultry diseases may differ between countries and geographical areas, there are few important diseases that are unique to particular parts of the world" (Biggs, 1982).
- At the global level, however, differences in distribution among regions are now apparent, because genetic variants have emerged within some of the major specific pathogens of chickens. This has become important for attempts to prevent the spread of virulent strains through international movements of poultry products. Table 1 shows the regional distribution of different biotypes of some important pathogens in 2008. ***Inter-regional variation in the distribution of pathogen strains of higher virulence will become more significant in trade, as the poultry industries of developing countries enter export markets.***

Avian pathogens in the future

Emerging pathogens are those for which recognition continues to occur over time (see Information Note on "Emerging Pathogens of Poultry Diseases). These pathogens arise through various ge-

TABLE 1

Regional distribution of higher-virulence strains of major poultry pathogens in 2008

Pathogen	Africa	Asia	SE Asia	Australasia	Europe	Near East	Americas	
							North	South
Avian leucosis virus (ALV)-J (see Information note 1)	+	+	+	-	-	+	-	+
Avian influenza (HPAI) (high pathogenicity)	+	+	+	-	-/+	+	-	+
Infectious bursal disease virus (IBDV)								
vv strains	+	+	+	-	+	+	-	+
variant strains	+	+	+	-	-	+	+	+
Newcastle disease virus (NDV) high virulence	+	+	+	-	+	+	-	+
Ornithobacterium rhinotracheale (ORT)	+?	+	+	-	+	+	+	+
Salmonella enteriditis PT4	+?	+	+	-	+	+	-?	+
Turkey rhinotracheitis (TRT) virus	+	+	+	-	+	+	+	+

Source: Bagust, 2008, Avian Health Online™.

netic mechanisms, including mutation, recombination or co-evolution with vaccines (e.g., Marek's disease virus) or the medications used (e.g., coccidiostats). ***There is a very high probability that several new poultry pathogens will emerge during the next ten to 20 years.*** The most likely candidates are pathogenic variants of avian ribonucleic acid (RNA) viruses, specifically those causing infectious bronchitis, Newcastle disease, infectious bursal disease and avian influenza, as well as a hypervirulent form of Marek's disease caused by an avian DNA (herpes-) virus, which is arguably the most challenging disease to control in intensive poultry industries worldwide.

Developed poultry industries are characterized by on-site biosecurity programmes, which are designed to prevent or minimize incursions by known infectious diseases. These programmes are supported by close veterinary and laboratory surveillance for poultry health. A newly emergent disease can therefore most likely be recognized quickly in any developed poultry industry. ***However, in countries where poultry production sites still lack adequate biosecurity programmes and access to competent veterinary services with laboratory backup, the economic consequences and time needed to identify, control and resolve the problem are much greater.*** The danger is that one or more emerging pathogens become established within a country's poultry populations and then continue to pose a threat as an endemic infection.

The costs of diseases within a country's poultry industry

Using figures from the United States, Biggs (1982) reported that the total economic costs of disease (including vaccines and condemnations) were about 20 percent of the gross value of production (GVP) and about three times the cost of losses from mortality. An analogous 2007 analysis conducted by the University of Georgia, United States, calculated that the GVP of the United States poultry industry in 2005 was US$28.2 billion, and disease losses were 8.2 percent of this. Both studies showed that for each US$1 000 loss due to mortalities, another US$2 000 is lost elsewhere owing to depressed productivity resulting from disease.

There is little information on the economic consequences of poultry diseases in developing counties. Hence one of the future challenges for these industries will be to organize the health infrastructure needed to conduct such analysis. Another will be to move from using frank mortality rates as an economic indicator of losses, to accounting for and then countering the high losses of productivity that result from health-related sub-optimal production.

Infrastructural capacity to diagnose the main causes of disease losses accurately will therefore prove necessary for countries seeking to develop a sustainable poultry industry.

POULTRY PATHOGENS AND THEIR MAJOR MEANS OF TRANSMISSION AMONG POULTRY PRODUCTION SITES

Table 2 lists 25 of the major infectious poultry diseases worldwide. Based on World Organisation for Animal Health listings (OIE, 2000), these are recognized globally as the diseases of most concern, because of their economic effects on commercial poultry production and their potential for negative effects on trade.

The diseases that are of the highest risk of accidental introduction into farms are denoted by ». These pathogens possess inherent properties of high transmissibility, and have enhanced resistance to inactivation (loss of infectivity) due to environmental temperature and sunlight. Such pathogens therefore tend to occur more frequently on poultry sites. Table 2 summarizes the major route(s) of transmission for each of the major pathogens. Knowing the means of spread of any pathogen is fundamental to the development of a plan of action to prevent spread of the pathogen and outbreak of the disease within a production site.

The poultry diseases listed in Table 2 are those likely to be caused by a single specific pathogen. Competent avian veterinarians and the technical personnel who undertake poultry health servicing for farmers in a modern poultry industry must be able to identify or at least suspect these diseases in their classical or relatively uncomplicated forms.

Further disease effects

Respiratory disease complex: Under field conditions, pathogens often interact with not only the host (bird) and its environment, but also one another. For example, day-old chicks arriving infected from the hatchery (vertical transmission) and remaining chronically infected for life are susceptible to other respiratory diseases such as infectious bronchitis or Newcastle disease. Fine dust particles in the poultry house air can then combine with superinfection by *Escherichia coli* bacteria contribute to additional respiratory insults, which will produce the (multiple) lesions that are seen at autopsy for *complex respiratory disease*. Field disease interactions often also involve common immunosuppressive agents, such as infectious bursal disease, Marek's disease or chicken infectious anaemia viruses. These increase the complexity of the disease pictures clinically and the lesions observable at autopsy.

Immunosuppression significantly decreases the ability of young poultry to respond effectively to standard vaccinations, and also predisposes them to infection by other specific pathogens. However, sub-clinical immunosuppression is often not readily apparent to the farmer, and therefore a common "silent" cause of significant economic losses. Pathogens causing such infectious disease conditions are termed "erosive" for site productivity (Shane, 2004). In contrast, major pathogens with high death rates and rapid spread such as NDV, IBDV or HPAI, although generically termed "catastrophic" diseases, cause lower economic losses in the longer term than the lower-level but more pervasive and widespread erosive pathogens do. Immunosuppression results from a range of known infectious and non-infectious causes, as shown in Table 3.

To diagnose the cause(s), competent autopsies combined with systematic on-site investigations of flock production, vaccination history and management practices need to be undertaken. However, results from laboratory examinations will often be needed to confirm a diagnosis. The Information Note on "Poultry Disease Diagnosis: Field Skills and Laboratory Procedures" gives further details.

In the context of poultry health and disease control, ***the government of a country that aims to develop a sustainable modern poultry industry MUST THEREFORE also put in place competent field and veterinary laboratory capacity for the diagnosis of poultry diseases.*** There is a strong need

TABLE 2

Infectious poultry diseases, pathogens and their routes of transmission among production sites

Poultry disease	Agent	Main signs and lesions produced in diseases in the field	Major route of spread		
			Faeco-oral (and contact)	Aerosols (and contact)	Eggs
Avian mycoplasmosis	Bacterium	Respiratory disease, air-sacculitis (*M. gallisepticum*) lameness, joint lesions, *M. synoviae*		+	+
Fowl cholera »	Bacterium	Acute form – septicaemia Chronic infections are associated with respiratory and head lesions	+ (wild birds and vermin)	+	
Highly pathogenic avian influenza	Virus #	Respiratory disease and high levels of deaths: HPAI H5N1 human deaths		+	
Infectious bronchitis »	Virus	Respiratory and kidney disease, egg production drops		+	
Infectious larnygotracheitis	Virus	Respiratory disease (varying severities) and conjunctivitis		+	
Newcastle disease	Virus #	Respiratory and nervous system disease: conjunctivitis (humans)		+	
Turkey rhinotracheitis	Virus	Swollen head, egg production drops, pneumonitis		+	
Infectious bursal disease »	Virus	Illness and losses especially 3–5 weeks old, with immunosuppression related diseases e.g. poor growth, necrosis of wingtips, inclusion body hepatitis	+		
Avian leukosis and reticuloendotheliosis	Virus	Tumours stunted chickens, tumours			+ +
Mareks disease »	Virus	Paralysis of legs and/or wings, tumours viscera, skin, nerves, eyes		+ contaminated dander and feathers	
Fowl typhoid Pullorum disease	Bacterium Bacterium	Watery diarrhoea, bronze livers Sick chicks, ovary disease in adults	+ +		+ +
Poultry enteritis complex » (turkeys)	Virus (mixed)	Spiking mortalities, diarrhoea, weight loss and depression 1–4 weeks old	+		
Avian adeno Gp1 »	Virus	Inclusion body hepatitis broilers	+		+
Avian adeno Gp3	Virus	Egg drop syndrome in layers	Contact with ducks		+
Avian reovirus	Virus	Lameness, tendosynovitis	+		+
Avian chlamydiosis	Bacterium #	Infections of the spleen, liver and airsacs. Humans – precautions at autopsy!	+ Contaminated dust/aerosol		+
Campylobacter infection »	Bacterium #	Infections but not disease in chickens, Poultry meat serious source for humans	+		+
Paratyphoid Salmonella »	Bacterium #	Enteric infections in chickens and humans	+		+
END OF LISTING OF DISEASES OF TRADE CONCERN (OIE 2000)					
Avian encephalomyelitis »	Virus	Epidemic tremours in chicks, egg production drops in layers		++	
Chick infectious anaemia »	Virus	Anaemia and ill-thrift, then diseases of complex aetiology (causes) which are predisposed to by CIAV immunosuppression		++	
Infectious coryza	Bacterium	Nasal and ocular discharge, facial swelling, drops in egg production	+ (and spread via drinking)		
Fowlpox	Virus	Cutaneous lesions (dry) and wet forms	Transmission by mosquitoes		
Coccidiosis »	Eimeria	Dysentery, soft mucoid faeces. Blood in specific intestinal areas (7 chicken spp.)		+	

» Specific pathogens that are of highest risk of accidental introduction into farms.
Zoonotic poultry pathogen.

TABLE 3

Common causes of immunosuppression in poultry production

Infectious	Non-infectious
Infectious bursal disease	Stress
Marek's disease virus	Poor nutrition
Coccidiosis *E. coli* bacteria	Mycotoxins, e.g. aflatoxins Ammonia
Newcastle disease virus	Dust
Chicken infectious anaemia virus	Improper use of antibiotics
Fowl cholera *Pasteurella multocida*	Vitamin deficiency, e.g. A, C, E

Source: Horrox, 2000.

for close collaboration between the public and private sectors in achieving this important goal.

SITE BIOSECURITY: THE PRIMARY KEY TO POULTRY DISEASES CONTROL AND PREVENTION IN COMMERCIAL PRACTICE

Avian pathogens, which comprise disease-causing bacteria, viruses and protozoan parasites, do not recognize national boundaries, only production sites and their disease control circumstances.

The most important measure for sustainable and profitable production on a poultry site is therefore to have forward defences in place – i.e., a biosecurity programme whose components (see

Information Note on "Site Biosecurity and Supporting Strategies for Disease Control and Prevention") work together to *reduce the risk of introduction of poultry pathogens* into a production site. For further and pathogen-specific protection measures, the farmer will also need to have correctly applied vaccination programmes for the dangerous (catastrophic) poultry pathogens that are known to be active in that region, such as Newcastle disease virus and virulent infectious bursal disease virus strains. Through this, disease outbreaks can largely be prevented, even if such pathogens gain entry to the site. A second tier of vaccinations – such as against some major immunosuppressive and respiratory disease agents (profit-erosive) – is also highly desirable. For poultry disease control, the most common problem on sites in many developing countries is their overreliance on vaccinations, rather than investing to achieve effective site biosecurity. The primary approach to poultry health on a production site should be to attempt to EXCLUDE diseases, rather than allowing relatively ready entry of a pathogen to flocks and then attempting to reduce its effects by immunoprotection, i.e., vaccination.

POULTRY HEALTH: NETWORK BUILDING IN A DEVELOPING COUNTRY.

Why should a network approach be taken to poultry health?

Because the real challenge for a developing country is to build sustainable poultry disease control systems that can focus and integrate their available professional poultry health resources. Although personal and political networks are often strong, professional health networking and the sense that industry personnel are working with the government sector to achieve common agreed aims can be much less evident. Fragmentation and duplication of resources and services, along with disagreements as to which (and how) areas of weakness must be strengthened, can mean that little real improvement of overall poultry health is achieved.

A distinguishing feature of the poultry health services in developed countries is the regular exchange of information among industry veterinarians (although their companies will be commercial competitors), government health services (laboratory and field) and often the universities in a region. Such communication and cooperation occur regularly, for example, quarterly within a soundly developed industry, because it is recognized that the mutual benefits of communicating about poultry health matters far outweigh the collective losses from silence.

How can the government agencies of a developing country position themselves to accelerate the development of a poultry industry?

Experiences gained in developed poultry industries worldwide have demonstrated that investing State resources in a ***central poultry health facility/unit with designated functions*** can provide an integrated special-purpose vehicle for delivering avian health-in-production services, as illustrated in Figure 1.

Government agencies and all industry stakeholders stand to benefit. ***Interaction between government and industry representatives is therefore essential for successful*** design and planning, and also later, when periodically reviewing the unit's performance in health and disease control. Industry might well contribute to financing this, for example, by providing funding for major pieces of laboratory equipment or other infrastructure that it expects will provide high benefit to itself. However, the guiding principle must be to achieve focused and integrated health functions for the unit to produce the health outputs needed to support sustainable poultry production in the developing country concerned. Avian veterinarians should also have pivotal roles in the poultry industry, through protecting both poultry and human health (see Information Note on "Veterinary Roles in Health and Knowledge Transfer across a Poultry Industry").

The primary thrust for senior government personnel, in partnership with industry, should be the planning of human resources to strengthen laboratory and extension skills for integrated activities that can deliver appropriate health services across the four sectors of the country's poultry industry. Proof of success will be visible evidence of the private sector choosing to use government services.

Investment in the construction of large purpose-built buildings or a stand-alone new facility should not be seen as the primary aim of this exercise. However, some low-cost special-purpose additions to an existing laboratory may significantly enhance the functional capacity of that unit. Examples could include the strengthening of microbiological health surveillance, or a simple building for secure maintenance of a small specified pathogen-free (SPF) poultry flock. Production of SPF eggs and chickens can then enhance local investigations, including with experimental reproduction of field diseases.

The overriding goal for the central poultry services unit is to be accessible and cost-effective for the veterinary and technical personnel who service commercial poultry production operations, particularly small and medium-sized farming enterprises. The modus operandum should be fee-for-service.

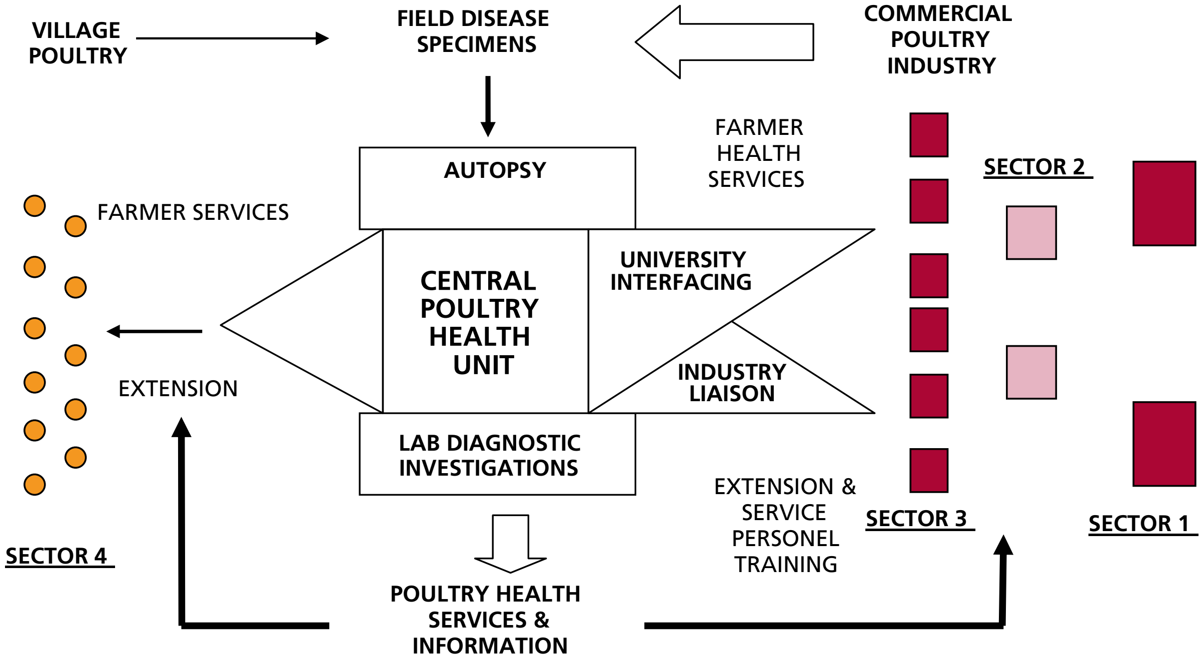
There will however be a clear responsibility for the services provider to direct and develop its staff resources adequately, to ensure that the services offered are relevant to the needs of the developing industry. The interfacing of industry and government poultry health production activities can then help to drive both (Bagust, 1999; Information Note on "Veterinary Roles in Health and Knowledge Transfer across a Poultry Industry"). For developing countries, there is another interesting development prospect: if government laboratory-based services are of sufficient quality, the large-scale intensive industrial operators (Sector 1 in Figure 1) may choose to pay for using those services. This scenario is not a fantasy – in Viet Nam some industrial poultry companies have been submitting samples to a government regional diagnostic laboratory on a fee-for-service basis, thereby gaining access to the expertise of government staff in enzyme-linked immunosorbent assay (ELISA) serological testing.

When quality services are achieved, additional benefits will begin to flow at the national level.

First, the central poultry unit will provide a natural focus for poultry health planning by industry and government, through its functioning in laboratory services, disease intelligence and field extension-outreach. Second, it can also act as a viable interface for health intelligence between commercial industry sectors (Sectors 1, 2 and part of 3 in Figure 1) that have the commercial imperative and economic means to minimize the risk of disease introduction, and the village (family) poultry sector (Sector 4 in Figure 1), which is often viewed as an important reservoir of path-

FIGURE 1

Delivery of the health services needed for support of poultry industry growth in a developing country



ogens of risk to commercial sectors. Although village-based poultry are clearly quite separate from commercial enterprises, it will be vital to include this sector in health services and surveillance. Family-based village poultry production is currently undertaken by a majority of families in rural regions in many developing countries, and contributes very significantly to poverty alleviation and food security.

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RECOMMENDED TEXT

For a sound overview of poultry diseases in the field, their causes and diagnosis:

Pattison, M., McMullin, P.F., Bradbury, J.M. & Alexander, D.J., eds. 2008. *Poultry diseases*, sixth edition. Philadelphia, Pennsylvania, USA, Saunders Elsevier. 611 pp. ISBN: 978-0-7020-2862-5.

Emerging pathogens of poultry diseases

Trevor J. Bagust*, Department of Avian Medicine, Faculty of Veterinary Science, University of Melbourne, Australia*

WHAT IS AN EMERGING PATHOGEN AND HOW IS IT RECOGNIZED?

Emerge = "to come forth into view from concealment or obscurity in background". (Macquarie Dictionary, Macmillan publishers)

As opposed to a specific pathogen that is known to be present as the cause of a recognizable poultry disease, an emerging pathogen is a specific microbe that can be shown to be the causative agent of a disease that:

i. has been recognized previously, but the cause has remained unclear; or
ii. is a new disease syndrome that has not appeared previously.

The usual sequence of events in the emergence of a disease generally starts with a novel disease becoming apparent to industry veterinarians and supporting diagnostic laboratories in a country, or sometimes simultaneously in several countries. Serological and virological investigations will often exclude the obvious involvement of currently known poultry pathogens. If the disease losses caused by this new pathogen are likely to be significant, further investigations will be undertaken in the research laboratory to clarify the pathogenesis of infection, means of transmission, immunity mechanism, and potential for vaccine development or eradication, depending on which is the most appropriate approach.

Cultivation of the microbial agent outside the host will usually permit serological screening to establish the prevalence of infection in flocks. Diagnostic investigations may include retrospective studies of previously unresolvable field disease problems, such as avian leukosis (subgroup-J) (Example 1).

The nature and intensification of the poultry industry make it seem likely that high numbers of specific pathogens will have to be excluded or prevented by vaccination at production sites, and that many pathogens will have arisen or been recognized as emerging in recent decades.

The industry is not unique in this regard among the intensive animal industries (pigs, poultry and fish), but pathogen-host dynamic interactions occur on a huge scale and are frequent within the poultry industry globally. Among production animal species, poultry have a uniquely short generation interval and must be reproduced continually, with probably about 100 million individual animals a day across the world's poultry industries. Vaccination is an essential measure for protecting poultry stocks against a range of dangerous pathogens, and during this protection process, the host's immunity continually exerts selection pressure on these poultry pathogens.

Viral pathogens, particularly those with ribonucleic acid (RNA) genomes (e.g., infectious bronchitis, Newcastle disease, infectious bursal disease viruses, and avian retroviruses such as avian leukosis virus), are all susceptible to the development of point mutations during replication of the genome. These viruses appear to lack effective proof-reading mechanisms for control of viral translation and repair of mutations during replication. Payne (2001) estimates that the rate of point mutations in avian retroviruses is as high as one per million virions, occurring within just one twelve-hour cycle of replication.

As viruses are continually mutating, so it must be accepted that new virus strains and disease problems will emerge in the future.

Several examples of poultry pathogens that have emerged in the last decade or so are given in the following, along with a brief explanation of the mechanism(s) involved in their emergence.

Example 1: Avian leukosis (subgroup-J) virus

This pathogen developed by genetic recombination in the field between two avian retroviruses. Between 1995 and 1998, neoplasms were observed in young breeders, leading to major losses of broiler breeders worldwide. This was due to primary breeding companies having genetic stock contaminated with ALV-J, the progeny from which were then exported to more than 50 countries. Retrospective virological and serological examinations by Payne (2001) and his laboratory group showed that this virus was circulating in the United Kingdom as early as 1989, with infections in some flocks sporadically producing tumours then in broiler breeding stocks.

Example 2: Newcastle disease.

The emergence of virulent NDV from lentogenic strains of Newcastle disease in Australia from 1999 to 2001 has been closely investigated and scientifically proven using molecular epidemiology.

Example 3: Highly pathogenic avian influenza.

Because of its zoonotic potential, the emerging poultry disease of greatest concern worldwide has been avian influenza, whether HPAI H5N2 (China, Hong Kong Special Administrative Region in 1999 and 2001) or HPAI H5N1 (in Asia from 2003 onwards, spreading to some 60 countries worldwide). This pathogen has subsequently been eradicated from all developed poultry industries, but is persisting as an endemic infection of poultry in several continents.

THE MECHANISMS FOR A POULTRY PATHOGEN'S EMERGENCE

Genetic changes

These can occur in a pathogen through accumulation of point mutations in the genome or even recombination and reassortment of gene sequences. These changes sometimes result in an altered pathogen with the ability to multiply more effectively in the host. Initially these changes may not be recognized, but as the mutant strain of the pathogen multiplies, becomes better adapted to the host, and spreads within flocks and among production sites, disease problems can become apparent – emerge – against the background of normal expected levels of losses during production activities.

The co-evolution of viral pathogens with their vaccines and medications

As do any other organisms, poultry pathogens tend to change and evolve. Antigenic change results from genetic control, and can be accelerated under immune pressure. Immune responses are geared to controlling pathogens, and include antibody production and T-cell activation against pathogen-specific protein structures, which are those most likely to change over time. Medication with antibacterial or anticoccidial drugs exerts similar effects over time. Continued treatment against coccidiosis or bacteria with the same unchanging drugs, especially with sub-therapeutic doses, tends to promote the emergence of resistance to those antimicrobial or anticoccidial drugs.

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Poultry disease diagnosis: field skills and laboratory procedures

Trevor J. Bagust, *Department of Avian Medicine, Faculty of Veterinary Science, University of Melbourne, Australia*

FIELD SKILLS

It is extremely important to apply a *systematic* approach when conducting field investigations. An autopsy (necropsy) is essential for avian veterinarians or technical services personnel seeking to establish a preliminary diagnosis. The autopsy also allows samples to be collected and submitted to a diagnostic laboratory for confirmatory testing. Samples collected may include blood, serum, plasma, swabs, feathers, tissues, scrapings or smears, as needed for confirmation or exclusion of the potential causative pathogens. Excellent video-based information on practical procedures for clinical examination and sample collection can be accessed at http://partnersah.vet.cornell.edu/.

Two of the best general-audience articles available on flock health and poultry diseases diagnosis were published in the international poultry industry technical periodical *World Poultry* (Yegani , Butcher and Nilipour, 2005a; 2005b). These articles can be accessed directly by using the hyperlinks shown for each.

LABORATORY PROCEDURES

The following comments confirm and extend the key information in these two articles.

Serology is the most frequently used of the three diagnostic approaches. However, it should be noted that detection of antibody can only be an indicator of previous exposure to a pathogen. Serology is nearly ideal for application in flock health surveillance, as laboratory testing can be conducted quite readily, for both the collection and the examination of large numbers of samples from multiple flocks. Serological activities in flock health surveillance may also include monitoring the effectiveness of vaccination programmes.

Microbiological investigations – bacteriology and virology: Yegani, Butcher and Nilipour (2005b) explain briefly where these tests are used in the modern industry. The following are their main advantages and disadvantages:

Histopathology is relatively economical, quick and useful for obtaining results, and the samples are easy to collect, store, transport and process. The downside of histopathology is that once a set of samples has been placed in fixative, the culture and typing of a pathogen is usually not possible.

Microbiology, whether bacterial or viral, it is invaluable for the isolation and culture of pathogens. However, the practitioner must exercise care to avoid cross-contamination when collecting the samples, and to prevent inactivation of infectivity during transport to the laboratory.

Routine aerobic bacterial culture is not expensive, other types of culture and typing usually are.

Culture of avian viruses is sometimes required, especially when field disease presentations are atypical or the emergence of a variant form of a viral pathogen (e.g., infectious bronchitis virus) is a possibility. The disadvantages of virus culture are that it requires time – often about a week – and using culture systems is moderately expensive.

PCR (polymerase chain reaction): This test system is highly sensitive and specific, which can be a problem. If the reagents (e.g., the primers) used are not an exact match with the pathogen in question, false negatives will occur. False positives, through contamination while a test is in progress in the laboratory can also be a problem.

Note: No laboratory test can return perfect results every time, and laboratories are not infallible. Veterinarians and technicians should always keep in mind the point made by Yegani, Butcher and Nilipour:

> ***"It is important, when investigating poultry production-health problems, that you do NOT rely SOLELY on the results of diagnostic tests".***

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Site biosecurity and supporting strategies for disease control and prevention

Trevor J. Bagust*, Department of Avian Medicine, Faculty of Veterinary Science, University of Melbourne, Australia*

BIOSECURITY PROGRAMME FOR COMMERCIAL POULTRY PRODUCTION SITES

- Keep poultry in a fully enclosed area, to which entry by other people is physically restricted by having only one point of access. This access point should be enterable only through a footbath containing disinfectant.

In general, casual visitors to a poultry production site should be discouraged. Records should be kept of all visits.

THE MOST COMMON BREAKS IN BIOSECURITY OCCUR WHEN INFECTIOUS POULTRY DISEASES ARE INTRODUCED BY THE MOVEMENTS OF PEOPLE.

- Prevent contact with wild birds and vermin by physically excluding them from the site, for example, with bird netting.
- The poultry keeping area and equipment within it must be kept clean, and be disinfected every few months. Cleaning followed by disinfection is essential between batches of poultry. Concrete rather than earth flooring in poultry production areas greatly increases the effectiveness of cleaning and disinfection.
- Equipment should NOT be shared among poultry sites. If it is absolutely necessary to share items, the equipment must be thoroughly cleaned AND disinfected before and after entering any poultry production site.
- Contamination of food and water by faeces should be strictly avoided.
- Feed should be stored in secure, lidded containers; the water supply should be decontaminated, for example, by a standard chlorination treatment.

Birds and health:

- Birds should be sourced from a breeder whose bird health status is known to be good, and should be of healthy appearance on arrival at the site. The new birds being introduced should be kept separate and be the last fed every day for an initial quarantine and observation period of one month.
- Potential signs of diseases, which should be known by the farmer, can include:
  - dullness, reluctance to drink or eat;
  - diarrhoea, respiratory distress, a sudden drop in egg production;
  - inability to walk or stand, abnormal position of head, neck or wings;
  - sudden illness and/or death of several of the birds in a group.

BIOSECURITY PROGRAMMES ARE BASED PRIMARILY ON QUARANTINE OF A SITE COMBINED WITH MEASURES FOR STRINGENT HYGIENE AND DISINFECTION.

The strength of this approach is that it can be applied generally to exclude from a site ALL important diseases (see Table 2 in "Poultry Health and Disease Control in Developing Countries") apart from those that are egg-transmitted.

More specialized disease prevention and control measures to support biosecurity on a site include:

Vaccination and medication: Diseases for which these may be applied include almost all the ones listed. However in every case, the vaccine being used will be effective for the prevention of ONLY that specific disease.

Eradication can be applied for egg-transmitted pathogens ONLY. The pathogens for which commercial eradication programmes have been successfully applied are avian mycoplasmosis, avian leukosis and reticuloendotheliosis viruses; fowl typhoid; and Salmonella pullorum.

Immunogenetic resistance to disease is promising for Marek's disease, but is not yet commercially available.

BIOSECURITY FOR VILLAGE PRODUCTION – SMALL-SCALE SEMI-SCAVENGING POULTRY FLOCKS (NON-COMMERCIAL)

Although it is not possible to apply full site biosecurity where numerous small poultry flocks are moving about in or around common areas in a village during daylight hours, modified elements of biosecurity can be applied.

As a minimum, housing should be provided to shelter and protect birds from predators at night time.

Improved poultry health can also be achieved by combining two other general approaches:

- *The development of central higher-quality hatchery-based services for the supply of day-old chicks*

  Irrespective of whether the poultry stocks being supplied to farmers in a country are of an indigenous or a commercial genotype, the laboratory screening of breeding stocks for freedom from infection, followed by the application of enhanced hatchery hygiene programmes should enable freedom to be assured from at least pullorum disease and fowl typhoid. Chicks supplied can also be protected early in their life against catastrophic diseases such as Newcastle disease and infectious bursal disease virus before leaving the hatchery (Bagust, 1998), by having high levels of maternal antibody, which can be assured by undertaking vaccination of the parents.

- *Strengthening extension services for training farmers in health and production*
  Poultry health and production extension services can quite quickly be systematically upgraded by applying information from other developing countries, such as Bangladesh, on strategies/ programmes that have proven successful in practice.

SUPPORTING STRATEGIES FOR CONTROL AND PREVENTION OF POULTRY DISEASES

The illustration of a classical building below shows that the columns (the pillars) are needed to support the roof, while the roof both holds the pillars together and protects the integrity of the building. The whole building represents the production site, and the pillars are the individual supporting activities that are integrated into an overall biosecurity programme.

The pillars represent the major technology-based approaches currently available for the control and prevention of infectious diseases of poultry. From left to right, the order of the pillars represents how widespread their use should be, starting with approaches that are suitable for widespread application, and moving towards those that are suitable only for specific uses. Thus, while quarantine, hygiene and disinfection are universally applicable against poultry pathogens, vaccination can be widely, but not always, used and eradication is currently feasible only for a few pathogens.

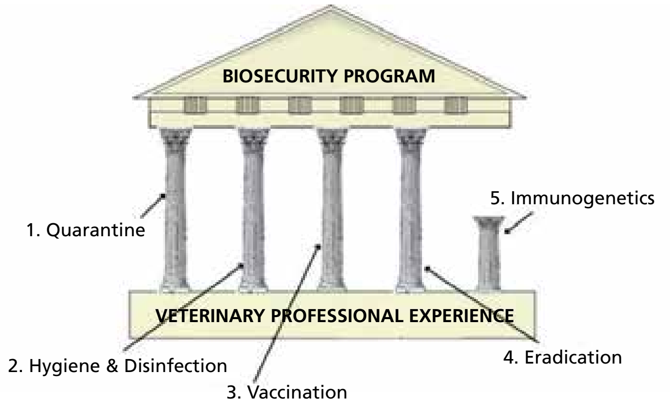
Pillar 1 – QUARANTINE: Currently, genetically based disease resistance is rarely of practical use in the field. This means that isolation is the only option. This is the oldest of the approaches, and dates back to Roman times (*quaranta* is Latin for 40), when a 40-day isolation period was enforced before a plague ship crew could enter a harbour or town.

Pillar 2 – HYGIENE AND DISINFECTION – complements quarantine. When flocks are being isolated from the entry of microbes, hygiene and cleaning are the first measures used. These ***must result in the removal of organic material from the surfaces to be decontaminated***, for example, in poultry houses or the hatchery, if antimicrobial disinfection treatment is to be effective.

Pillar 3 – VACCINATION is probably the easiest and most economical group of methodologies used for the control and prevention of poultry diseases in poultry production. However, it should NOT be used as the sole measure on a flock.

Pillar 4 – ERADICATION is a feasible disease control option for only some specific poultry pathogens. The criteria to be met are usually that the major mode of transmission is via the egg and that relatively accurate and inexpensive lab tests have already been developed for detection of infection. Although a successful eradication programme requires major investments of resources, significant benefits can flow back to industry over the longer term.

Pillar 5 – IMMUNOGENETIC RESISTANCE to disease is not yet complete, but – as the case of Marek's disease virus demonstrates – it may soon become so. The solution may lie in the hands of commercial primary breeding companies, because genetic selection could be applied to disease resistance, should a commercial need create pressure for this. At present, however, this is not seen as a high priority relative to other growth and production parameters. In addition, there is a lack of effective tools for selecting for specific resistance to many major infectious poultry diseases.



Veterinary roles in health and knowledge transfer across a poultry industry

Trevor J. Bagust*, Department of Avian Medicine, Faculty of Veterinary Science, University of Melbourne, Australia*

VETERINARY ROLES IN HEALTH (POULTRY AND HUMAN HEALTH)

As shown in Figure 1, the supply-and-demand forces within the market place provide the major driving force for development of modern poultry production. Any commercial enterprise seeking continuing success in the marketplace must therefore:

1. minimize its costs of production;
2. ensure that its products are safe for human consumption.

Veterinarians also have to fulfil these dual responsibilities in a modern intensive poultry industry by:

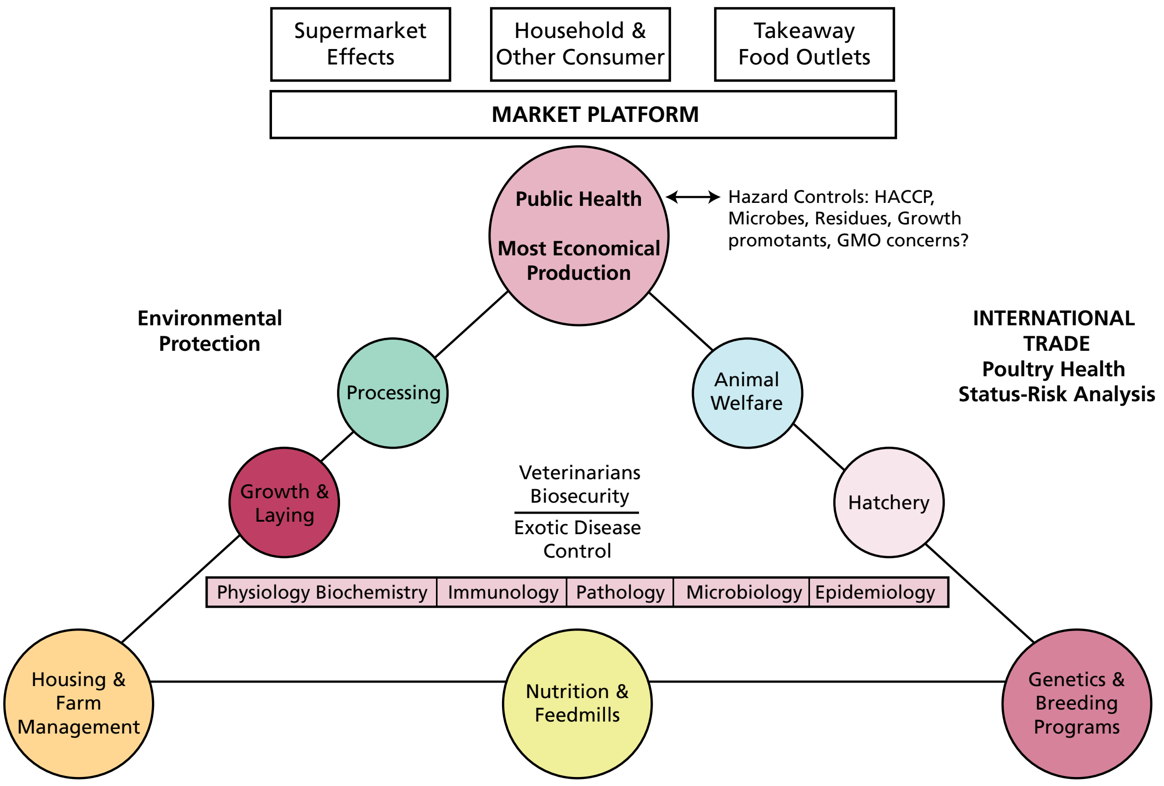
- ***Achieving the most economical poultry production***
  The veterinarian's role in poultry health involves close collaboration with several other professionals working in key roles in the poultry production operation.
- ***Achieving product quality for protection of public health***
  The veterinarian also has a role in ensuring that poultry products are free from zoonoses (infectious diseases transmissible from animals to humans, such as Camplyobacter, Salmonella and listeriosis) and that they are microbiologically safe and free from environmental residues. Experience proves that the profitability of a food industry or commercial organization is very quickly undermined by problems with unsafe poultry products.

AVIAN HEALTH-IN-PRODUCTION: PROFESSIONAL DEVELOPMENT AND KNOWLEDGE TRANSFER

Veterinarians are trained to develop their capabilities for understanding animal diseases, as well as the causes, prevention and control of a range of pathogens. To this end, veterinary undergraduate education includes the scientific disciplines of *physiology and biochemistry, immunology, pathology, microbiology* (including serology) and *epidemiology* – the science of the transmission of infectious diseases. Veterinarians need formal knowledge and

FIGURE 1

The roles and important interaction points (~~~) with other production professionals for poultry veterinarians operating in a modern intensive poultry industry



Source: Bagust, 2006; Avian Health Online™.

training in these disciplines so that they can understand and investigate problems in avian health. Avian veterinarians are also responsible for ensuring that appropriate *poultry health knowledge* is transferred to the technical personnel who share responsibilities in poultry production.

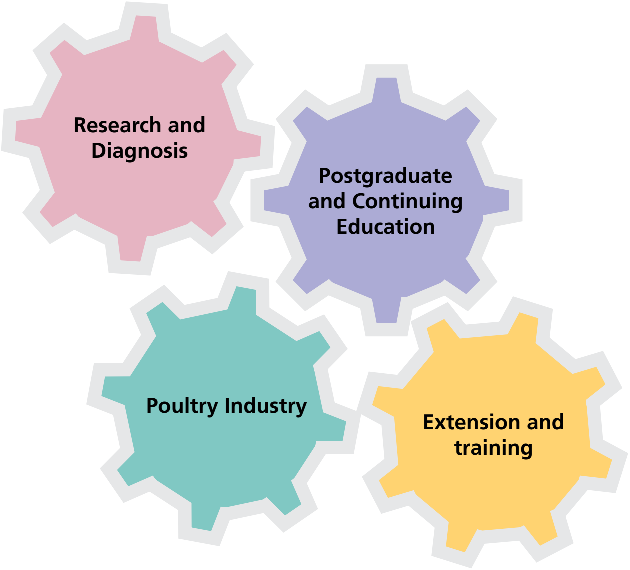
Avian veterinarians and other technical services personnel working in developing countries may wish to achieve higher levels of expertise in the performance of their commercial activities. Advice and guidance on undertaking professional development to internationally accepted standards of competency is available from relevant professional international bodies, such as the World's Poultry Science Association (www. wpsa. com) or the World Veterinary Poultry Association (www. wvpa. net).

Figure 2 illustrates how all the activities undertaken in poultry production can work together to achieve sustainable progress in an industry.

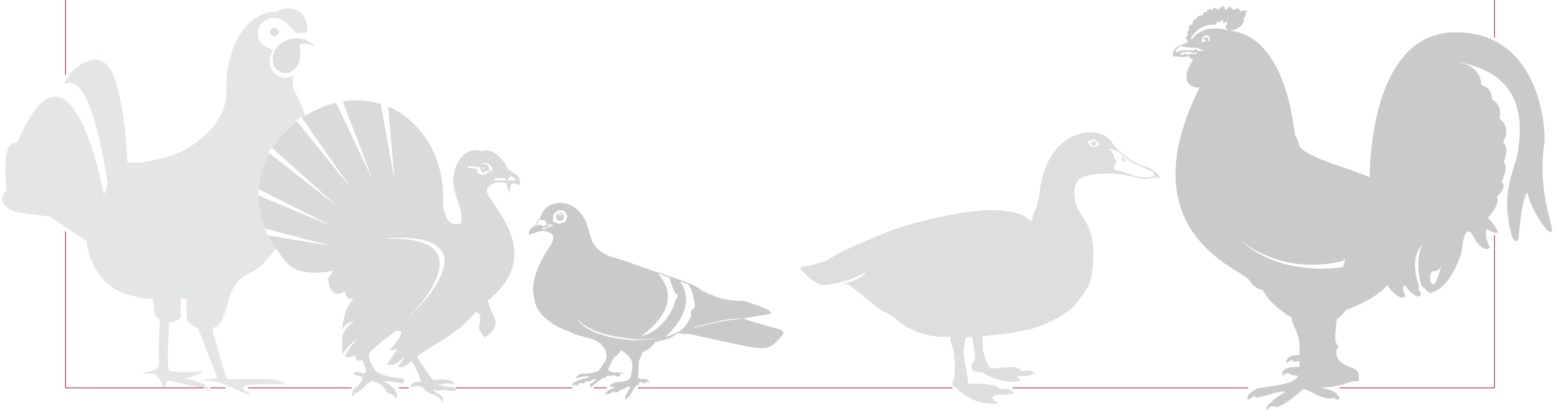
The wheels of knowledge transfer shown in Figure 2 are lubricated by communication and interfacing among the personnel involved, so in a country seeking to develop an effective and efficient poultry industry, it is essential that personnel learn to operate in this cooperative manner. A national networking structure is the logical starting point for achieving sustainable poultry health in production, particularly through strengthened control of infectious poultry diseases.

FIGURE 2

The wheels of knowledge transfer in a poultry industry



Poultry welfare in developing countries



Poultry welfare in developing countries

Christine Janet Nicol and Anna Davies*, School of Veterinary Science, University of Bristol, Bristol, United Kingdom*

WHY IS POULTRY WELFARE IN DEVELOPING COUNTRIES A CONCERN?

The poultry sector is one of the most rapidly growing livestock sectors worldwide: between 1961 and 2001 the number of poultry slaughtered annually increased by 621 percent. Although industrialized countries have much higher average per capita consumption of most poultry products, production in developing countries is increasing rapidly. In 2000, Compassion in World Farming reported that average annual egg production in developing countries had increased by 331 percent since 1980.

Although chickens are very different from people, it is thought that they are capable of suffering from states such as pain or frustration. Ethical consideration therefore needs to be applied to poultry farming, and ways of ensuring good welfare for such large numbers of animals need to be found.

WHAT IS ANIMAL WELFARE?

The *Oxford English Dictionary* associates welfare with "well-being; happiness; and thriving or successful progress in life". In relation to animals, different cultures emphasize different aspects. Thus, people from different backgrounds give different relative importance to animal welfare factors such as: i) health and normal biological functioning; ii) the subjective "feelings" of the animals; and iii) the animals' ability to live a natural life (EFSA, 2005).

The World Organisation for Animal Health (OIE) definition of animal welfare refers to how well an animal is able to cope with the conditions in which it lives (www.oie.int/eng/normes/mcode/en_chapitre_1.7.1.htm). This definition, derived from Broom (1986), has widespread, but not universal, acceptance. Other authors continue to emphasize the importance of animals' feelings and experiences in their definitions of animal welfare (Phillips, 2009).

For the purposes of this review, the concept of animal welfare refers to an animal's overall state of well-being. OIE considers that good animal welfare requires disease prevention and veterinary treatment, appropriate shelter, management, nutrition, humane handling and humane slaughter/killing. In general, many different components of an animal's state must be considered to judge whether its welfare is good or bad. Some of the components that FAO considers important are that the animal should be healthy, comfortable, well nourished, and safe. It is also important that animals are able to express behaviours that are priorities in a captive environment (Weeks and Nicol, 2006) and that they should not suffer from unpleasant mental states such as pain, fear and distress (although these feelings cannot be measured directly). When considering animal welfare as a whole, it is important to take each of these components into consideration.

MEASURING ANIMAL WELFARE

The state of an animal's welfare can range from very good to very bad (Duncan and Fraser, 1997). Sometimes, however, one component of welfare is good but others are not. For example, an animal might be in good health but its ability to move may be restricted by caging or tethering. It is therefore important to be able to measure each component of welfare, and to devise ways of integrating the different measures to reach an overall conclusion.

The Five Freedoms, principles and criteria for good welfare

In the United Kingdom, the welfare of farm animals has been considered a formal discipline since 1965, when the Brambell Committee suggested that farmed animals should have five basic "freedoms" of movement, such as the freedom to stretch and the freedom to turn around. These can be considered the original components of animal welfare. However, they are rather narrow, so to take account of a broader range of animals' physical and behavioural needs, these Five Freedoms were modified in 1979 by the United Kingdom's Farm Animal Welfare Council (FAWC, 1979), which proposed that all farm animals should have:

1. freedom from hunger and thirst;
2. freedom from discomfort;
3. freedom from pain, injury and disease;
4. freedom to express normal behaviour;
5. freedom from fear and distress.

The Five Freedoms have been highly influential, and OIE accepts them as one of the guiding principles governing animal welfare. They are also referenced in most European welfare legislation, referred to by veterinary and animal welfare organizations worldwide, and form the basis for OIE Terrestrial Animal Health Code Article 7.1.1. However, they also have drawbacks. In particular, it is not easy to decide which normal or innate behaviours are important for animals in captive environments. Recently, the European Welfare Quality consortium (www.welfarequality.net/everyone) has expanded and clarified the components of animal welfare, proposing a set of four principles and 12 criteria, as shown Table 1.

Resource-based and animal-based measures

Once the principles and criteria for good welfare have been agreed, ways of measuring each criterion need to be devised. These measures can be used on farms or other livestock enterprises to assess animal welfare. Early assessments of animals on farms were made by observing whether key resources (e.g., nests or clean drinkers) were present; such measures are called resource-based measures. However, the presence of a resource does not mean necessarily mean that it is being used effectively. Recently, there has therefore been a move to make direct observations and measurements of the animals themselves, using animal-based outcome measures. This is important to ensuring the good welfare of all individual animals within a flock or herd.

TABLE 1

Welfare principles and criteria as defined by Welfare Quality

Welfare principles	Welfare criteria
Good feeding	1. Absence of prolonged hunger 2. Absence of prolonged thirst
Good housing	3. Comfort around resting 4. Thermal comfort 5. Ease of movement
Good health	6. Absence of injuries 7. Absence of disease 8. Absence of pain induced by management procedures
Appropriate behaviour	9. Expression of social behaviours 10. Expression of other behaviours 11. Good human-animal relationship 12. Positive emotional state

Much progress has been made in developing valid, repeatable animal-based outcome measures for chickens. The Welfare Quality Project has suggested appropriate measures that could be used to assess each of the 12 welfare criteria for poultry, and the majority of these are animal-based outcome measures. Thus, the absence of hunger can be measured by assessing emaciation on an agreed scale, and thermal comfort can be measured by assessing whether birds are panting or huddling. In drawing an overall conclusion about the welfare of chickens at a specific site, the measures for each criterion can be given different weights, with higher weights given to criteria that are thought to be especially important.

Scientific assessment of welfare

It is important that the measures used on farms to assess animal welfare are backed up by more fundamental scientific research, to ensure that they really do measure factors associated with quality of life. The scientific assessment of poultry welfare usually depends on measuring a range of physiological, behavioural or clinical indicators, and comparing these measurements among chickens that are housed or treated differently in some way. A broad range of indicators can be used to assess stress response and immune function in an attempt to measure whether the animal is coping with its environment or not. However, interpretation of these indicators is sometimes difficult. An alternative scientific approach has therefore been to examine the environmental conditions chosen by chickens. Early studies examined the environmental choices of chickens for food types, laying, foraging and exploratory materials, heat, lighting, and social conditions. The strength and importance of these preferences has recently been assessed by determining how hard chickens will work to obtain these resources or conditions when access becomes more difficult or demands more energy (Nicol, 2010). Important new scientific research is examining how welfare indicators and the environmental choices of chickens interrelate (Nicol *et al.*, 2009). The International Society for Applied Ethology is a scientific body with an interest in how animal behaviour can be used to assess animal welfare (www.applied-ethology.org/index.htm). Many other organizations are interested in the scientific assessment of welfare; their newsletters can be accessed via the FAO website: www.fao.org/ag/againfo/programmes/animal-welfare/en/.

INTERACTIONS BETWEEN WELFARE AND PRODUCTIVITY

It is often thought that good production will itself guarantee good welfare, but the relationship between production and welfare is more complex than this.

In the following two examples, welfare and production are positively associated:

(i) In some backyard, village environments, chickens may be able to express normal behaviour, but their overall welfare may be poor if they are affected by disease, parasitism or malnutrition. Addressing these welfare issues will also result in increased productivity.

(ii) In many cases, acute or chronically stressful events will reduce productivity. For example, moving hens from pens to cages produces a marked short-term decrease in egg production. Similarly, chronic stress can impair immune function and lead to increased disease and mortality, and reduced production.

However, in the next two examples, welfare and production are in conflict:

(i) Intense genetic selection for production traits can have adverse consequences on other aspects of bird health. For example, laying hens selected for high egg production have increased skeletal problems (see information note on "Welfare issues in commercial egg production"), and broiler chickens selected for very high growth rates have problems with leg health and lameness (see information note on "Welfare issues in commercial broiler production").

(ii) Restricting the quantity of feed fed to broiler-breeding flocks/birds is a normal management method because egg production and hatchability are poor if female breeding birds are fed *ad libitum*. However, this means that the birds experience chronic hunger (see Information note "Broilers").

SAFE-GUARDING ANIMAL WELFARE

When production gains can be achieved by improving animal welfare, as in the first two examples above, there should be no need for any other mechanism to safe-guard animal welfare; addressing issues of health or malnutrition will benefit both farmers and chickens. This is why poultry welfare is being integrated into food safety policy, based on scientific evidence that well-treated animals are generally healthier and more productive than badly treated ones (European Commission, 2002). OIE also recognizes the links between welfare and animal health and is introducing guidelines for the transport and slaughter of farmed animals. However, when increased production conflicts with good welfare, other checks and balances are required to ensure that the animals are not suffering or unduly exploited. The mechanisms available to ensure good welfare in these circumstances include the law, codes of practice and voluntary assurance schemes.

POULTRY WELFARE AND THE LAW

The extent to which poultry welfare is protected by the law varies greatly. In 2000, the European Scientific Committee on Animal Health and Animal Welfare investigated international welfare standards and found no generally recognized, specific standards worldwide. Although there appears to be little legislation in the developing world concerning the welfare of farmed animals, many other countries have laws relating to acts of cruelty to individual animals. Significant progress has been made in the last ten years, particularly in non-European Union (EU) Europe (European Commission, 2002). Most legislation refers to the Five Freedoms (FAWC, 1979), but this may change if the expanded principles and criteria mentioned earlier become widely accepted. Increased legislation often follows increased public awareness of animal welfare issues.

There are two main approaches to introducing welfare legislation (European Commission, 2002). Binding codes are usually included within legislation, and it is a legal requirement to conform. An example of binding legislation in the EU is the Laying Hens Directive (1999). As part of an interim review of the scientific evidence required before adoption of the legislation, the European Food Safety Authority (EFSA, 2005) produced an opinion on the welfare aspects of all housing systems used for laying hens. Following this, the LayWel project, funded via the European Commission's Sixth Framework Programme and national funding from several EU countries, studied the welfare implications of different poultry farming systems. The scientific opinion derived from both these exercises provided the basis for banning conventional cages, summarizing evidence that conventional cages do not allow hens to fulfil behaviour priorities, and present a significant threat to the birds' skeletal health. The EU ban on conventional cages is scheduled to take effect from 1 January 2012. From that date, all cages must contain enrichment (furnishings to assist the birds in performing natural behaviours), such as an area for dust-bathing, and perches. The EU has also introduced a Broiler Directive (2007), which limits the stocking density at which poultry may be kept for meat production. Farmers will be able to keep broiler chickens at higher densities only when high welfare is exhibited and proved. This is likely to be assessed by looking at animal-based outcome measures such as mortality.

CODES OF PRACTICE

Non-binding codes of practice can be used alongside the law. Codes of practice establish recommendations for good practice as followed by competent and conscientious practitioners. Codes of practice can be particularly useful if they set out clearly what farmers *must* do to ensure good welfare (minimum standards), and what they can do further to optimize welfare.

SELF-IMPOSED CODES/ASSURANCE SCHEMES

In many countries, there are voluntary schemes for certifying that farm animals have been kept at specified welfare standards. Self-imposed codes are voluntary, but producers conform as they are likely to offer a marketing advantage. Examples include farm assurance schemes, which are common in Europe. They have been introduced in response to consumer demands that animal products satisfy certain safety, environmental and welfare standards.

HOUSING AND MANAGEMENT OF POULTRY

In developing countries, the majority of poultry are indigenous breeds, kept in small flocks living in a backyard, village environment. Gueye (1998) reports that approximately 80 percent of poultry in Africa can be found in traditional production systems. In these systems, birds are generally free-ranging and often scavenge or are fed household scraps. In this type of poultry production system there is no real distinction between birds reared for meat and those kept as egg layers. Poultry meat is typically obtained from males killed at between 12 and 20 weeks of age, and from egg laying birds that have ceased to be productive.

Many developing countries are now investing heavily in more intensive commercial systems of poultry production to provide meat and eggs for growing urban and peri-urban populations. In these systems, egg laying hens and broiler meat chickens are genetically very different from each other and from the indigenous breeds kept in small family flocks by villagers in rural areas, and are kept and managed differently.

Intensive broiler production systems obtain chicks from commercial hatcheries, and then house them in flocks in floor-based systems until they reach slaughter weight, when they are caught, transported and slaughtered at a specialized abattoir. Intensive egg production systems also obtain chicks from commercial hatcheries, but these chicks are usually kept in large rearing flocks until they reach sexual maturity and start to produce eggs. At point of lay, the pullets are transported to the adult housing system, which contains egg-handling facilities. A great range of adult housing systems exists, including conventional cage, furnished cage, single-tier aviary, multi-tier indoor, and free-range (described in www. laywel.eu). At the end of the commercial laying period, generally at around 18 to 24 months of age, these birds are caught, transported and slaughtered in specialized facilities.

MAJOR WELFARE ISSUES

Poultry welfare is affected by genetics, by the hatching, rearing and adult housing environments, by the methods of transport and slaughter employed, and to a great degree by the attitudes and standards of care of the stockpersons.

Welfare issues in a village environment

In the village environment, birds are mainly indigenous breeds, which are generally better able to cope with the natural environment than those breeds that have undergone extensive genetic selection for production traits. However, disease transmission is high in backyard poultry systems, often resulting in low productivity and high mortality. Newcastle disease is one of the most problematic and widespread diseases in both village and intensive production systems. Vaccines have been developed, but not all farmers have access to them, and vaccinating free-ranging poultry can be a challenge (FAO, 2001).

Another challenge facing small-scale poultry producers in developing countries is the availability of appropriate nutrition. Many smallholder farmers and their families have limited food, and are thus unable to provide feed for their small scavenging chicken flocks. Poultry frequently also lack access to a source of clean and cool water. This is a welfare concern for the poultry and for the people rearing them, as productivity will be low. In hot climates, birds may have difficulty staying cool if natural or artificial shelter is not provided, as all chickens are derived from jungle-living birds and they actively seek shade.

Most of these welfare issues can be addressed by improved veterinary care and nutrition and the provision of simple facilities such as clean drinking-water and shade.

Welfare issues of broilers in commercial production

The major welfare issues for commercially reared broilers are leg health problems and lameness, metabolic disorders, and hunger in restricted-fed broiler breeder flocks.

Welfare issues of laying hens in commercial production

The major welfare issues for commercially reared laying hens are bone problems such as osteoporosis and the high incidence of resultant bone fracture, behavioural deprivation resulting from housing in cage systems, unequal access to facilities for birds housed in non-cage systems, and injurious pecking and plumage loss, which occurs in all types of housing system.

Welfare issues during transport and slaughter

The major welfare issues arising during transport and slaughter are high levels of stress due to inappropriate handling, and pain and stress if birds are not properly stunned before slaughter.

BENEFITS OF IMPROVING ANIMAL WELFARE

FAO recognizes the importance of animal welfare practices that lead to benefits for both people and their animals, and supports their implementation, recognizing that the welfare of humans and the welfare of animals are closely linked: www.fao.org/ag/againfo/resources/en/pubs_awelf.html

Consumer acceptance

Throughout the world, people are becoming increasingly aware of the importance of farmed animals' welfare (European Commission, 2002). Consumers are interested in the origin of their poultry products, and surveys such as Euro-barometer show that most people believe that the broiler and laying hen industries need to improve the current level of bird welfare:

http://ec.europa.eu/food/animal/welfare/survey/sp_barometer_fa_en.pdf.

Consumers' perception of animal welfare can affect the type of products purchased; 43 percent of consumers say that they consider the welfare and protection of meat animals before they make a purchase.

Access to markets

At present, the World Trade Organization (WTO) operates a free-trade policy and will not allow countries to restrict trade because of differing standards of animal welfare. This is becoming a concern within the EU, however, where there are guidelines relating to animal welfare to which farmers must conform. The EU is pushing for welfare to be included in the WTO multi-lateral trade negotiations. If this happens, imported products will have to meet basic EU standards to enter this market.

Employment

Improvements in animal welfare can create work in countries where employment is difficult to find. It is particularly important that intensification is coupled with increased labour, as one of the best ways of raising animal welfare standards is to improve inspection and handling practices. Intensification without increased labour may result in welfare problems being overlooked. In many developing countries, poultry are raised by women and children. Learning how to raise poultry to optimal welfare standards can help women to improve their productivity, and may help alleviate poverty. Organizations such as the International Network for Family Poultry Development and the Network for Small-holder Poultry Development are helping village women to make their poultry enterprises more productive, efficient and profitable. This has a positive impact on the empowerment of women and provides them with social contact both within and outside the village.

The model farm project set up by the World Society for the Protection of Animals and the Food Animal Initiative also aims to help farmers in developing countries to rear their animals in ways that will provide them with optimal economic outputs. A number of farms have been set up in China, where high-welfare animals are reared to organic standards and receive a premium when sold. The farms provide training for producers and exemplify a viable alternative to intensive farming.

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Welfare issues in commercial egg production

Christine Janet Nicol*, School of Veterinary Science, University of Bristol, Bristol, United Kingdom*

This information note considers aspects of welfare that have been highlighted as concerns within commercial egg production (Perry, 2004; EFSA, 2005; LayWel, 2006). First some issues affecting chicks and growing pullets are mentioned, before discussing the most significant issues facing adult laying hens.

CHICKS AND PULLETS

Disposal of male chicks

When chicks are hatched for egg production, only females are needed. Male layer strain chicks have no commercial value, which means that 50 percent of the chicks hatched have to be killed. Their disposal raises practical and ethical issues. Methods of disposal vary from region to region and country to country. In all cases, the aim should be to ensure that every male chick is killed humanely and instantaneously.

Chick handling

Whether chicks are to be reared for meat or egg production, it is important that they are handled with care in the hatchery. After being taken from the hatching trays by hand, chicks may either be sexed and sorted manually, or placed on a conveyor from which the males (often with different sex linked feathering rate or feather colour) are removed for slaughter. The female chicks are then placed in disposable chick boxes with perforated ventilation holes, for transport to the rearing houses.

Variation in chick or pullet sizes

The aim of the hatcheries and farms that supply pullets should be to produce birds of even body-weight and size. Variation in size can result in later problems of aggression, poor performance and injurious pecking.

LAYING HENS

Osteoporosis

Osteoporosis in laying hens is a major welfare concern. It is the progressive loss of structural bone throughout the skeleton, which results in weakened bones. Weakened bones can lead to a high number of birds suffering keel, leg and wing fractures, which are likely to be painful. Osteoporosis can also cause birds to become paralysed, which can lead to death. Loss of structural bone in hens begins around sexual maturity and continues throughout the laying period. The process is accelerated in caged systems, which prevent birds from exercising. Fleming *et al*. (2006) found significant improvements in bone strength when birds were housed in aviaries, rather than battery cages. Nutrition also appears to affect bone strength, and the effects of osteoporosis can be minimized by providing sufficient calcium, phosphorus and vitamin D in the diet. Another contributor to the severity of osteoporosis is genotype. Some genetic strains appear to be more susceptible to osteoporosis than others. It has been suggested that it is possible to select genetically against osteoporosis while still maintaining a high egg yield, but this has not been attempted on a commercial scale.

Keel fractures

One consequence of osteoporosis is that it greatly increases the susceptibility of bones to damage and fracture. In laying hens, the bone most likely to sustain a fracture is the keel bone, which can be damaged in two main ways: i) by misjudged landings when birds are perching or nesting in a furnished environment; or ii) when birds are handled during depopulation at the end of lay. The incidence of keel fractures caused by furnishings is higher in non-cage systems than in cage systems. In free-range and single-tier aviary systems (barns), the mean prevalence of bone breakages is 65 percent, 90 percent of which are keel bone breaks (Wilkins *et al*., 2004). These findings are of particular importance in the EU, where conventional cages are being banned in 2012. However, the incidence of new breaks – those caused during depopulation – is higher in conventional cage systems than in other systems. This may be attributed to weaker bones in caged birds, due to lack of exercise. Access to the birds within the cage (i.e., the size of the aperture) and the manner in which the birds are withdrawn from the cage during depopulation are critical factors in determining bone breakages.

Behavioural restriction

In 1999, the EU introduced the Laying Hens Directive, stating that all hens must be housed in an enriched environment from 2012 onwards. This has involved the introduction of furnished cages, which will replace conventional caged systems. Furnished cages will provide birds with a nest, perches and pecking/scratching mats. A recent study comparing the physical and physiological condition of birds in four different housing systems for layers in the United Kingdom concluded that these aspects of bird welfare are better in furnished cages than in any other system (Sherwin, Richards and Nicol, 2010)

The importance of providing nests, perches and pecking areas stems from the natural behaviour of chickens. In the wild, poultry have the ability to build nests, scratch and peck, dust-bath and perch. These are all behaviours that have not been lost through genetic modification of poultry breeds and they are still important for good welfare of modern-day laying hen (Weeks and Nicol, 2006). In conventional cages, it is virtually impossible for hens to perform these behaviours. Hens also need at least 600 cm^2

each to be able to stretch their wings and perform other comfort movements. Furnished cages do not allow birds total behavioural freedom, but they do allow birds to perform their most important behaviours to a degree not possible in conventional cages.

Non-cage systems permit even greater freedom of behaviour for the majority of birds in a flock. In large flocks of hens, however, some birds' access to facilities such as nests and perches is restricted by other birds, and aggression can be common. A small proportion of birds in non-cage systems can be excessively persecuted by their flock-mates. These so-called "pariah" birds have extremely poor welfare.

INJURIOUS PECKING

Injurious pecking in laying hens is a major welfare concern that can spread through flocks, resulting in pain and high mortality. Injurious pecking can occur in all types of layer hen housing. In cage systems persecuted birds are unable to escape, but the problem tends to be confined to particular cages. In non-cage systems, once injurious pecking starts it can spread rapidly throughout the whole flock. Injurious pecking comprises feather pecking, vent pecking and cannibalism.

Feather pecking

Gentle feather pecking occurs when one hen pecks at the feathers of another, without pulling or removing the feathers. Severe feather pecking occurs when feathers are pulled violently or removed. The relationship between these two types of feather pecking is not clear, and they appear to have distinct risk factors. There may be a number of reasons for the onset of feather pecking, including deprivation of natural behaviours such as ground pecking (Rodenburg and Koene, 2004). The inability to perform behaviours can lead to long-term frustration, which may result in arousal, aggression or fear. Any of these emotional states may increase the likelihood that a hen will start feather pecking. There are clear genetic influences on feather pecking (Rodenburg *et al*., 2008), and epidemiological studies have identified a range of important environmental risk factors. Bald patches on hens, where feathers have been removed, encourage further pecking of exposed body tissue. This has an economic impact on production, as birds lose energy and heat and therefore consume more food. Feather pecking is likely to be very painful for the affected hens, and may lead to cannibalism. The risks of feather pecking can be reduced by feeding mash rather than pelleted diets; providing additional foraging and fibre sources, such as chopped straw and vegetables; and ensuring good litter condition, to encourage birds to peck the litter rather than each other. Reducing light intensity is a short-term measure that does not address the cause of the problem.

Cannibalism

Cannibalism occurs when the flesh or blood of another individual of the same species is consumed. It is a common problem in poultry, particularly laying hens (Newberry, 2004). Cannibalistic behaviour may be learned by hens, and the problem can spread rapidly throughout a flock. Cannibalism can arise as a result of severe feather or vent pecking, which often occurs due to frustration. Producers have attempted to reduce the incidence of feather pecking and cannibalism by beak trimming, which involves removal of up to two-thirds of the upper beak. This process is likely to cause pain, and does not combat the root of the problem. Some producers raise birds at low light intensities so they do not have the visibility to perform cannibalism. This has not been effective however, as the increased light levels needed to inspect birds are associated with cannibalism. Beak trimming has been banned in a number of countries, so an alternative is needed. Providing birds with enrichment, such as litter to peck at, may reduce frustration. It is also important to provide pullets with litter in their rearing environment. Cannibalism is also positively correlated with mineral, protein and energy deficiencies, so providing all nutritional requirements may reduce cannibalism. Selection of genetic strains that are not predisposed to cannibalism should also be encouraged.

Vent pecking

As with feather pecking, vent pecking can lead to cannibalism. Vent pecking is directed at the tissue around the cloaca (see photo).

This may be investigative behaviour to begin with, but once established can lead to birds pecking at internal organs or tissue. The result is often death. It is therefore advantageous to prevent birds from viewing the cloacal areas of other birds, by ensuring that nesting areas are not brightly lit and that there are sensible perch arrangements. It is also important not to bring the flock into lay too early – vent pecking can be triggered when small birds are encouraged to lay large eggs too early.

Emaciation

The metabolic demands of high egg production are great, and by the end of lay many hens show signs of emaciation, poor body condition and chronic stress. This can be minimized by ensuring that a good diet with adequate levels of nutrition is supplied towards the end of the laying period.

AVOIDING WELFARE PROBLEMS IN HENS

Several sources provide advice on avoiding welfare problems in layers. These include national government codes of practice, such

Varying severity of vent damage in laying hens as the United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA) code www.defra.gov.uk/corporate/consult/broiler-welfare/annex-g.pdf, and assurance schemes guidance, such as the Royal Society for the Prevention of Cruelty to Animals (RSPCA) Freedom Food scheme, which details and specifies high standards of management and provision: www.rspca.org.uk/servlet/Satellite?pagename=RSPCA/RSPCARedirect&pg=welfarestandards&marker=1&articleId=1123153964606.

The following are some important practical tips for avoiding welfare problems:

- Avoid conventional unfurnished cages, as these cannot provide good welfare for laying hens.
- If using a cage system, use furnished cages with at least 600 cm^2 of floor area per bird and a nest area. Manufacturers of furnished cage systems are listed in the LayWel project description of laying systems: www.laywel.eu/web/pdf/deliverable%2023.pdf.
- Produce plans for preventing or coping with emergencies such as equipment breakdown or fire.
- Inspect flocks at least twice a day and check individual birds, even in cage systems where it can be difficult to observe individual birds at the back of a cage. At monthly intervals, catch samples of birds to look more closely for problems such as mite infestations or vent pecking.
- Keep good records of mortality and the causes of mortality. Record spontaneous mortality separately from culling figures.
- Seek veterinary advice if birds show signs of sickness. There are many links between poor welfare and poor health/disease. Improving one can often improve the other.
- If possible, obtain birds from rearing units close to the laying farm, as this will minimize stress during transfer. The new laying flock will settle more easily and early egg production is likely to be improved.
- Do not bring the flock into lay too early. Onset of lay at 17 or 18 weeks is associated with a greater risk of vent pecking than onset of lay at 19 weeks.
- Do not place perches at heights that permit one bird to peck another bird's vent.
- The use of mash rather than pelleted feed allows the hens to spend a longer time feeding, and reduces the risk of injurious pecking.
- The provision of good, dry litter to a depth of at least 10 cm is vital for the good management of hens in non-cage systems.
- For birds in non-cage systems, provide a raised slatted or wire mesh area separate from the litter area. Do not provide high perches, which are associated with "crash-landings" and subsequent bone fractures.
- In non-cage flocks, the risk of injurious pecking can be reduced by ensuring that the litter area is kept dry and friable. Add fresh litter regularly and, if possible, provide hens with additional pecking materials, such as straw or other dry vegetation.
- If the birds have access to an outdoor range area, encourage them to go outside as much as possible, by providing areas of shelter (from sun or rain) on the range. This reduces the risk of injurious pecking in the flock.
- Birds should have at least eight hours of light and at least six hours of dark in every 24-hour period, and light levels should not be less than 10 lux. In non-cage systems, consider providing brighter light over the litter areas, to encourage birds to forage and dust-bath, and lower light levels near the nest boxes and perches, to reduce the risk of vent pecking.

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Welfare issues in commercial broiler production

Christine Janet Nicol, *School of Veterinary Science, University of Bristol, Bristol, United Kingdom*

This information note considers three aspects of welfare that have been highlighted as concerns within commercial broiler production (Weeks and Butterworth, 2004): leg health, metabolic disorders, and hunger in breeding birds. General issues of health and disease are considered elsewhere (see review on Poultry Health and Disease Control in Developing Countries).

LEG HEALTH

The incidence of leg disorders is a major issue in broiler production and often leads to lameness. The most recent large-scale study in the United Kingdom found that 27.6 percent of the birds assessed close to slaughter age showed poor locomotion, and 3.3 percent were almost unable to walk (Knowles *et al*., 2008). These figures arose even though the participating farms had good culling procedures, with severely lame birds identified and killed humanely to avoid further suffering. A similarly high prevalence of lameness has been found in other studies around the world over the past 15 years. Assuming the worldwide prevalence of leg disorders is similar to that in the United Kingdom this equates to 12.5 billion broilers experiencing leg problems worldwide per year. Although breeding companies are directing far more attention and resources to finding ways of selecting against leg disorders, negative correlations with meat yield can sometimes hinder progress.

There are several causes of lameness in broiler chickens, broadly divided into infectious and developmental causes, although the two are interrelated. One of the main factors contributing to both types of leg problems is genotype. Through intensification of production and genetic selection over the last 50 years, broiler growth rates have increased from 25 g per day to 100 g per day – a 300 percent increase. Owing to the rapid growth of broiler chickens, it is possible for them to reach slaughter weight at less than 40 days of age. The problem is that this rapid growth places stress on the skeleton, resulting in skeletal abnormalities. Rapid growth can result in valgus varus deformation, ruptured tendons, separation of the proximal epiphysis, bending and rotation of the tibia, osteochondrosis, degenerative bone disease and microfractures. It has also been demonstrated experimentally that rapid growth increases the risk of a range of infectious leg conditions including arthritis and tenosynovitis. Generally, the risk of lameness increases rapidly with bird age, up to the point of slaughter. The innervation of chicken legs is similar to that in humans, so leg disorders may be painful to poultry (European Commission, 2000) and some causes of lameness may be associated with more pain than others. When birds are given analgesic (pain-killing) drugs, their walking ability generally improves. In addition, one study showed that lame birds preferentially select food containing an analgesic drug, a feeding pattern not observed in non-lame birds, which suggests that birds might actively seek to control their own pain levels.

Environmental and management factors that increase the risk of chickens developing lameness include diet, lighting regime and antibiotic use (Knowles *et al*., 2008). It is also generally accepted that stocking density has an effect on lameness, although there is conflicting evidence. Dawkins, Donnelly and Jones (2004) report that other environmental and management factors such as air and litter quality within the house may have more of an effect on bird welfare than stocking density. Nonetheless, high stocking density does seem to exacerbate other welfare problems, and the EU Broiler Directive (2007) sets limits on stocking density for farms where leg health problems are apparent.

Lameness is not the only leg problem affecting broiler chickens. Contact dermatitis (pododermatitis) appears to be increasing in prevalence in some countries. Signs of contact dermatitis include the appearance of lesions, ulcers or scabs on the footpads (see photo), hocks or breast. In severe cases, extensive areas of skin may turn black. This results from these parts of the birds' bodies being in prolonged contact with irritant substances derived from faeces, such as ammonia. Lesions can act as a gateway for bacteria, which may spread through the bloodstream and cause joint inflammation.

METABOLIC DISORDERS

There are a number of problems associated with poultry metabolism, and they often have a genetic cause. The major issues result from a very high metabolic rate, efficient feed conversion and rapid growth. Rapid growth places pressure on poultry's internal organs. This can lead to cardiovascular diseases, the most prevalent of which are ascites and sudden death syndrome. Ascites is the accumulation of fluid in the lungs and abdomen caused by

Varying severity of footpad dermatitis in broiler chickens deficiency of the cardio-pulmonary system in adequately oxygenating the blood pumped through the large muscle mass of the modern-day broiler chicken. This can result in right-side ventricular failure. The condition appears to be more prevalent at high altitudes, although it affects birds worldwide. In 1996, a worldwide survey estimated the incidence of ascites in broilers to be approximately 4.7 percent. Selection based on oximetry or serum levels of cardiac-derived Troponin-T has reduced the incidence of ascites in broiler flocks in recent years, but it is still an important cause of loss, accounting for up to 50 percent of total mortality in commercial flocks of birds reared to 42 days.

HUNGER IN BROILER BREEDERS

When considering the welfare of broilers it is important to consider all stages of production. The welfare of broiler breeders is often compromised by routine feed restriction. To compensate for the negative effect of selection for growth rate on reproductive performance, food is restricted during both the rearing and the laying phases to prevent birds from becoming too fat and heavy, which would compromise egg production and fertility. These birds are almost certainly experiencing extreme hunger, at least during the rearing phase, when they are often given less than half of their voluntary food intake

AVOIDING WELFARE PROBLEMS IN BROILERS

Several sources provide advice on avoiding welfare problems in broilers. These include national government codes of practice, such as the United Kingdom's Department for Environment, Food and Rural Affairs (DEFRA) code www.defra.gov.uk/corporate/consult/broiler-welfare/annex-g.pdf, and assurance schemes guidance, such as the Royal Society for the Prevention of Cruelty to Animals (RSPCA) Freedom Food scheme, which details and specifies high standards of management and provision (www.rspca.org.uk/servlet/Satellite?pagename=RSPCA/RSPCARedirect&pg=welfarestandards&marker=1&articleId=1121442811407).

The following are some important practical tips for avoiding welfare problems:

- Demand good stock from hatcheries, and contact the breeding companies if leg health problems are experienced.
- Produce plans for preventing or coping with emergencies such as equipment breakdown or fire.
- Inspect flocks at least twice a day, and check individual birds. Check that all birds can move freely with gait scores of less than 3 (gait scores are described in Knowles *et al*., 2008).
- Check that there are no signs of breast or leg lesions. Such symptoms are usually associated with wet and dirty litter. If lesions are apparent, take steps to improve litter condition and ventilation.
- Keep basic records detailing the number of birds in the house, maximum and minimum temperatures, etc.
- Keep good records of mortality and the causes of mortality. Record spontaneous mortality separately from culling figures.
- Birds that cannot move sufficiently well to have easy access to feed and water should be culled, as they are unlikely to recover and culling will prevent them from experiencing further suffering.
- Manage the litter, keeping it as dry and friable as possible. Do not allow ammonia levels to rise too high. Consider topping up the litter frequently, to allow birds to rest and dust-bath and to minimize the risk of skin lesions and ulcers.
- Avoid high stocking densities, as these are associated with depressed health and welfare.
- Providing perches at a height of 10 to 30 cm above the floor can improve leg health. Allow a minimum of 2 m of perch length per 1 000 birds.
- Average growth rates of more than 45 g per day from hatch to slaughter may be associated with welfare problems.
- Ensure that birds have a period of darkness in each 24-hour period, to allow them to rest.
- Make sure that wild birds, cats, dogs or rodents cannot enter the chicken house.
- Check for the appearance of panting, which may indicate that the birds are too hot. Good ventilation is essential. In hot climates, consider roof insulation as a way of reducing the impact on birds.
- Ensure that the house is thoroughly cleaned and disinfected between flocks.

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Transport and slaughter of poultry

Christine Janet Nicol, *School of Veterinary Science, University of Bristol, Bristol, United Kingdom*

DEPOPULATION

In the village environment, birds may be reared in small numbers and slaughtered as and when they are needed for food. In some ways, this system is better for welfare, as it does not require large-scale depopulation and transport. Birds can usually be caught from their night-time enclosures.

Depopulation on a larger-scale usually takes place during the night, when birds are easier to catch and therefore do not become as stressed by the process. Most large producers are responsible for providing both the catching team and the transportation for the birds. Catching teams are required to grasp large numbers of birds quickly and efficiently. Unfortunately, this often involves handling them incorrectly. The preferable method for handling chickens is to catch both legs simultaneously, to avoid hip dislocations and broken bones. However, owing to the speed at which the catching team works, it is usual for only one leg to be caught, which often results in painful leg dislocations. Birds are usually inverted when caught, so that many may be held in each hand simultaneously. This does not provide optimal bird welfare, as birds prefer to be held upright. These processes are likely to cause pain (Weeks, 2007) to the birds, so it is important that they are handled as carefully as possible to minimize the risk of damage.

Techniques are being developed for avoiding excessive handling of birds during depopulation. Automated "broiler harvesters" are large machines that depopulate broiler houses rapidly, by picking up chickens using revolving rubber fingers. Trials have demonstrated that they may halve the risk of catching damage to the legs (Weeks, 2007), but they can only be used in large clear-span houses. Similar good results can be achieved if birds are caught using gentle and correct handling techniques.

Cage systems for laying hens present special problems during depopulation, and injury and damage levels can be high, as birds have to be removed from the cage fronts. In the EU, attempts have been made to improve cage design so that birds can be removed more easily through the whole cage front, rather than through narrow gaps; this has resulted in a reduced incidence of broken bones sustained at the end of lay.

TRANSPORT

In developing countries, there are three main methods for slaughtering birds. The system in which they are reared determines whether and how they will be transported. Backyard village poultry are often slaughtered by their keepers, within the home environment, which does not require transportation. Larger producers however transport birds to either a "wet" market or a commercial abattoir. The range of transportation to each varies among countries and regions. In general, birds that are slaughtered in abattoirs are transported from the farm in large loose-crates or on modulated lorries, similar to those used in the EU. The stocking density is usually very high, as few legal guidelines exist. This poses a problem, particularly in very hot countries, where many birds may die of heat stress. A major welfare issue with this method of transport is the movement of birds from a controlled (relatively stable) environment to a lorry, which may provide birds with little protection from extreme climates.

In many developing countries, there is demand for fresh meat, and animals are often killed at markets in the presence of the consumer. Worldwide, billions of people buy their poultry at "wet" markets, many of which are unlicensed. Birds are often transported under stressful conditions. Small producers may utilize what little transport they have by tying poultry to the back of their bicycles or motorcycles, often in an inverted position, thus causing a high degree of stress.

SLAUGHTER

In large commercial abattoirs, chickens are generally stunned before being slaughtered. A stunning process causes immediate loss of consciousness, which lasts until death. Stunning in poultry is usually performed by passing an electric current across the brain, disrupting normal electrical activity and causing a loss of consciousness (HSA, no date). This enables them to be killed without feeling the pain associated with the slaughter process.

In large abattoirs, poultry arrive on lorries and are often kept in a lairage (holding area) before being killed. In extreme climates, this can be very stressful as birds are densely stocked and unable to cool themselves. Many birds may die before reaching the slaughter line, often through heat stress. Not only is this bad for

Highly stressfull transport of chickens the welfare of the birds, the economic loss can also be extreme.

Unloading takes place directly from modular or loose crates. Birds are inverted and hung on shackles by their legs. This is likely to cause pain, particularly for large birds, as the shackles are one-size and do not accommodate variations in bird leg size and shape. The shackles carry birds through an electrically charged water-bath stunner. It is essential that the stunner is monitored to ensure that it delivers enough electricity through the brain of each bird. Birds should be observed for the following signs of effective stunning: neck arched and eyes open; no rhythmic breathing; rigidly extended legs; constant rapid body tremors; and wings held close to the body (HSA, no date).

Following stunning, birds may regain consciousness if the brain has not been properly disabled. This makes it essential that birds are bled (by cutting the blood vessels in the neck) within 15 seconds after stunning. In the United Kingdom, it is a legislative requirement that at least one carotid artery is severed during neck-cutting. However, it is recommended that both carotid arteries and both jugular veins are severed, as death then occurs more rapidly.

SLAUGHTER OF VILLAGE POULTRY

In a village environment, poultry that are not transported to be sold at wet markets are likely to be slaughtered on demand within the village. It is likely that only a few birds will be slaughtered at a time, giving the slaughterer plenty of time to ensure that each bird is killed humanely. In wet markets, however, less time may be taken over slaughtering birds, and it is likely that a number are still conscious while being killed. Unlike in commercial abattoirs, stunning is rare at wet markets, although it is a legal requirement in a number of countries. An alternative to the water-bath stunner is a hand-held, low voltage stunner with electrodes that are placed either side of the bird's brain, passing an electric current through it (HSA, no date); however, this has not yet been widely adopted.

The methods of slaughtering poultry that are likely to be used in villages are neck dislocation, decapitation or delivering a concussive blow to the head (leading to loss of brain function). Although none of these methods provide pre-slaughter stunning, they are regularly used for emergency on-farm killing. Each of the three methods has welfare problems associated with it. If performed correctly, a concussive blow to a chicken's head may be the most effective way of killing it. To be effective, however, the blow must be very heavy and accurately directed to the bony part of the head, behind the comb. If delivered to any other part of the head, soft tissue may absorb some of the force of the blow, which may not result in concussion. For a concussive blow to be a reliable method of slaughter, it must be performed accurately and consistently.

Neck dislocation and decapitation must also be performed correctly to be effective methods of slaughter. Of the two, decapitation may be the more reliable, as it involves severing all the arteries supplying blood to the brain (the largest of which are the carotid arteries in the neck) immediately. This gives a very rapid loss of blood pressure, and death follows shortly after (HSA, no date). Neck dislocation involves stretching the neck to dislocate the spinal cord and cause damage to the surrounding blood vessels (HSA, no date). The procedure can be difficult to perform correctly and consistently, and does not always concuss the brain, causing insensibility. It is therefore not recommended as a routine method of slaughter (HSA, no date). As with the commercial slaughter of poultry, bleeding should be carried out immediately after either neck dislocation or producing concussion, to ensure that the birds are killed.

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