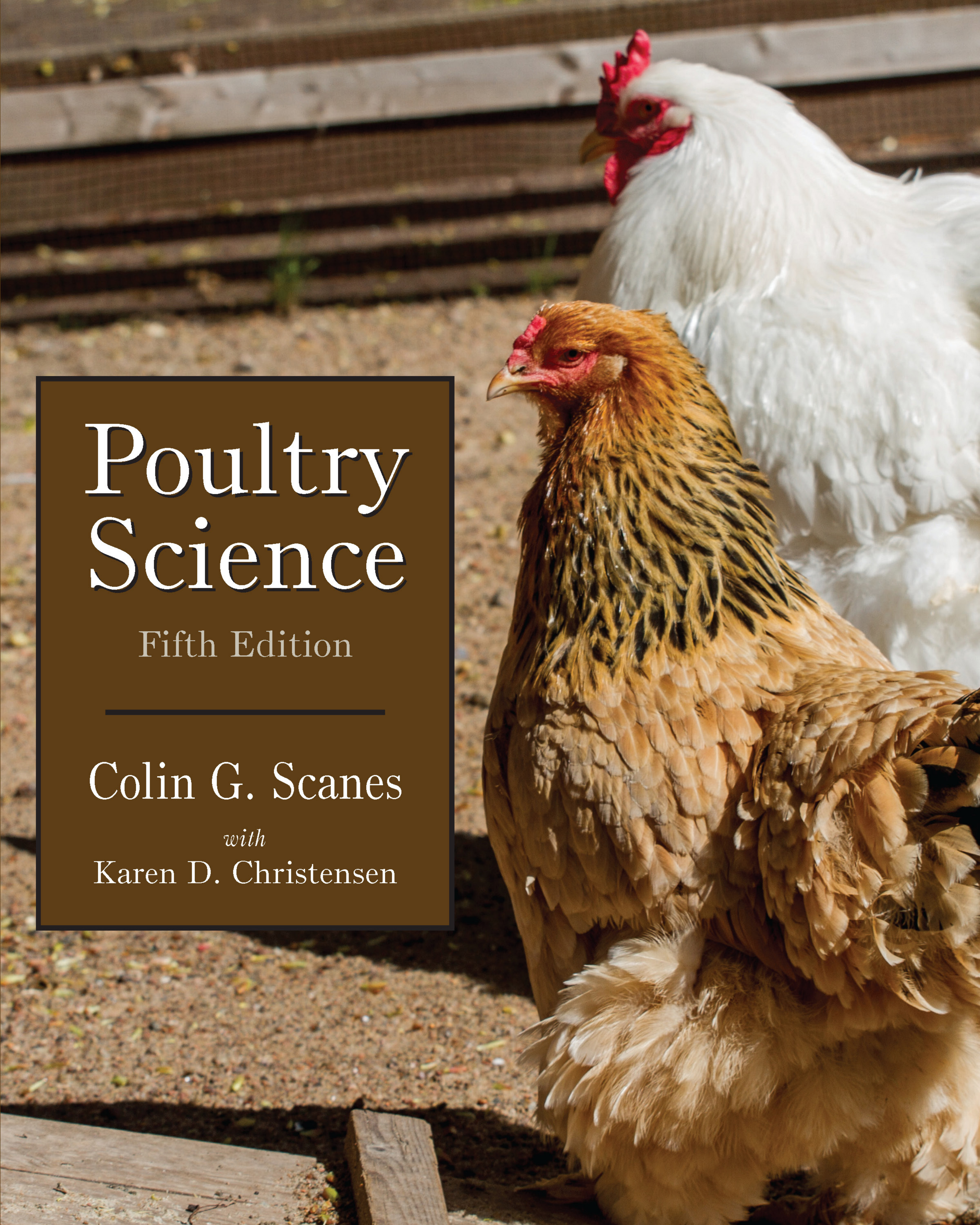

Poultry Science

Fifth Edition

Colin G. Scanes

with

Karen D. Christensen

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Dedicated to the outstanding present, past, and future students

studying poultry science

and to the excellent faculty teaching this.

May the pursuit of truth and service be your watchword.

About the Authors

Colin G. Scanes is an adjunct professor in the Center of Excellence in Poultry Science at the University of Arkansas. He was formerly a professor in the Department of Animal Science at both Iowa State University and Rutgers–The State University of New Jersey, and Department of Poultry Science at Mississippi State University. He was formerly on the faculty at the University of Leeds in the United Kingdom. He held administrative positions at Rutgers (Department Chair), Iowa State University (Executive Associate Dean of Agriculture and Associate Director of the Agricultural Experiment Station), Mississippi State University (Vice President for Research and Economic Development), and the University of Wisconsin–Milwaukee (Vice Chancellor of Research and Dean of the Graduate School). He was educated in the UK with a BS from Hull University and PhD from the University of Wales. He has published extensively in poultry and animal science, with 16 books and over 600 papers. He has received numerous awards, including awards for teaching and research (Rutgers), election as a fellow of the Poultry Science Association and of the American Association for the Advancement of Science, as well as an Honorary Professor at the Agricultural University of Ukraine and recipient of a medal from the University of Agriculture in Krakow. He has been a speaker for the United States Departments of State and Agriculture in Europe and the Middle East.

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Contents

Preface

The production of poultry continues to make tremendous advances. This book is thoroughly revised to reflect this.

The book is intended for multiple audiences:

1. A textbook for introductory poultry classes for undergraduate students (overlooking the "Deeper Dive" sections), particularly in North America, but also throughout the world.
2. A textbook for senior undergraduate/graduate students (embracing the research-based "Deeper Dive" sections).
3. An overview of poultry production for business and engineering students entering the poultry industry.
4. A useful compendium for poultry professionals, small- and medium-sized producers of poultry and game birds, and future farmers.

The utility of this textbook for introductory poultry classes is enhanced by the "Points for Discussion" sections. Moreover, the effectiveness of class instructors is undergirded by the research-based "Deeper Dive" sections.

Areas covered include global poultry production; commercial poultry production; poultry business organization; and production of meat chickens (broilers), turkeys, eggs, ducks, geese, game birds, and other poultry. In addition, chapters cover poultry biology, genetics, behavior, diseases/health, housing, ventilation, and processing. New or greatly expanded sections cover biosecurity; poultry stress/welfare; feed additives; food safety; incubation; controlling pests; poultry waste and environmental issues; brooding; internships and applying for positions; and organic, free-range, and niche poultry production.

Colin G. Scanes
2019

1

A Global Perspective on Poultry

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Define the term poultry.
2. Describe the domestication of the chicken.
3. Describe the domestication of the turkey.
4. Understand the importance of poultry in the world.
5. Know what the top countries and regions are for the production and export of chicken, turkey, duck, goose (meats), and eggs, both chicken and other eggs (essentially duck and goose eggs).
6. Understand why poultry production has increased globally.
7. Understand why the efficiency of poultry production has improved.
8. Comprehend the nutritional advantages and disadvantages of eating eggs and poultry meat in the diet.
9. List the nonfood uses of eggs, poultry, and coproducts.

1.1 Introduction

Poultry (see Figure 1.1) have been a part of human lives since at least the Neolithic Revolution. There has been tremendous growth in poultry and egg production globally (see section 1.4). There is high global consumer demand for poultry meat and eggs due to the following:

- The taste, flavor, texture, juiciness, and overall enjoyability of eating poultry meat.
- The versatility of eggs cooked as meals, into cakes, and in the manufacture of processed foods.
- Excellent nutritional content with high-quality protein, vitamins, and minerals together with relatively low fat (see section 1.5).
- Low price. Due to improvements in the efficiency of production, the price of poultry meat and eggs has declined relative to the ability of people to buy (see section 1.6).

Figure 1.1 Day-old chicks drinking from nipple drinkers. (Source: Omjai Chalard/Shutterstock)

TEXTBOX 1A

Word Origins Related to Poultry

The English language derives from a mixture of predominantly two languages: Old English (itself derived from Anglo Saxon, a West Germanic language) and Middle French (a Romance language derived from Latin). Both Germanic and Romance languages are Indo-European languages dating back to a common language (Proto-Indo-European) more than 5000 years ago.

Word origins related to poultry fall into three groups: (1) Derived from Old English, (2) derived from Middle French, and (3) others.

1. Poultry-related words derived from Old English.
   - Chicken, from Old English word *cicen* (chicken).
   - Chick ("baby" chicken), a diminutive[1] of *chicken*.
   - Cock (adult male chicken), from the Old English word *kok* (male chicken).
   - Cockerel (male chicken), a diminutive of *cock*.
   - Duck, from the Old English word *duce* (duck) (from the Germanic *ducan*, meaning "to dive").
   - Dove, from the Old English word *dufe* (dove).
   - Fowl, from the Old English word *fogul* (a bird or to fly).
   - Goose, from the Old English word *gos* (goose).
   - Hen, from the Old English word *henna* (female chicken).
2. Poultry-related words derived from Middle French.
   - Ostrich, from the Middle French word *ostrice* (ostrich).
   - Pigeon, from the Middle French word *pijon* (pigeon) (from the Late Latin *pipion*, meaning "a young bird," and from the Latin *pipire*, meaning "to chirp").
   - Poultry, pullet, and poult, from the Middle French *poult* (female chicken) (itself from the Lain *pullus*, meaning "small chicken").
   - Quail, from the Middle French word *caille*.
3. Poultry-related words derived from other languages.
   - Emu, from Portuguese *ema*.
   - Rooster (adult male chicken), from American English (bird that roosts). A replacement for the arguably offensive word *cock*.

[1] A diminutive is a nickname or shortened form of a name. For example, Kate and Sam are the diminutives for Katherine and Samuel.

The term **poultry** applies to domesticated birds. These are both a source of meat and eggs. Poultry include chickens, turkeys, ducks, geese, pigeons, guinea fowl, pheasants, quail, and other game birds, together with the ratites, ostriches, emus, and rheas. In the past, other species of birds such as swans and peafowl were eaten and included in the term poultry. For the etymology (origin of words) of poultry-related words, see Textbox 1A. Our understanding of domestication has greatly expanded through the application of the techniques of molecular biology to existing populations of domesticated and wild birds together with knowledge derived from archaeology. The domestication and early use of chickens and turkeys are considered in sections 1.2 and 1.3, respectively.

Definitions

Domestication: When people take wild animals or plants and breed them over multiple generations such that their characteristics are meeting human needs.

Poultry: Domesticated birds. Globally, the term today predominantly consists of chickens, turkeys, ducks, and geese. In addition, there is production of minor poultry species such as guinea fowl, pheasants, quail, and other game birds, together with the ratites, ostriches, emus, and rheas.

Poultry science: The study of all aspects of poultry, including production.

Poultry biology: The study of the biology of poultry and a facet of poultry science and avian biology.

Ornithology: The study of birds. This is derived from *ornis*, the Greek word for "bird."

Avian science: Another term for the study of birds. This is derived from the Latin word for bird, *avem*, and its plural, *aves*.

TEXTBOX 1B

Points for Discussion

1. Should we be eating meat and eggs?
2. Rather than eating poultry, meat, and eggs, we could be eating the ingredients of poultry feed (corn or other cereals, and soybeans as a source of protein). After all, they are highly nutritious. This is called the "food versus feed" argument.
3. What customs, traditions, or occasions are associated with poultry and eggs?
4. Do we eat only for nutrition? Do we eat only to sate our hunger? Do we eat for pleasure?
5. Share your favorite recipes and dishes.
6. Share some common dishes at restaurants.

Textbox 1C

A Deeper Dive: Hunger across the World

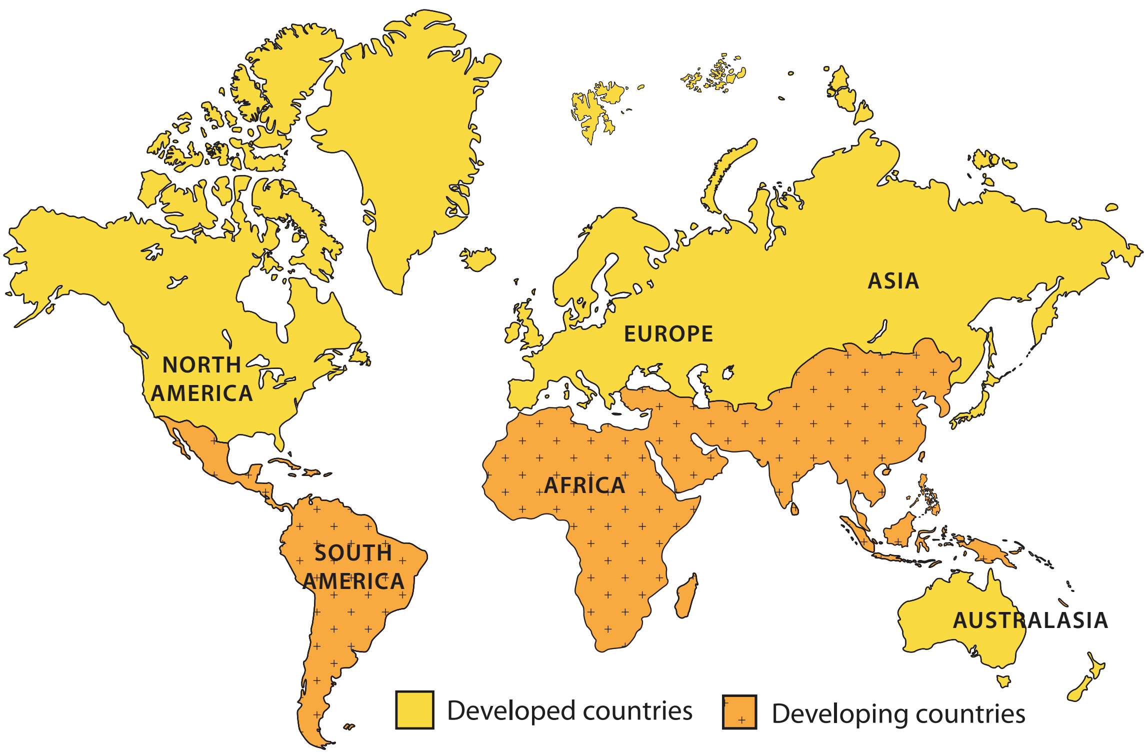
According to *The State of Food Security and Nutrition in the World 2017*, published by the United Nations Food and Agricultural Organization, between 1990 and 2016 there has been a decline in the percentage of people who are hungry. The magnitude of these improvements varies considerably between different regions of the world (see Textbox 1C Figure 1).

- Developed regions remained at < 5%.
- Developing regions declined from 23.3% to 12.9%.
- Africa declined from 27.6% to 20.0%.
- Latin America declined from 14.7% to 5.5%.
- Asia declined from 27.6% to 12.1%. More specifically, Central Asia declined from 14.2% to 7.0%, Eastern Asia from 23.2% to 9.6%, Southern Asia from 23.9% to 15.7%, South Eastern Asia from 30.6% to 9.6%, and Western Asia from 14.2% to 8.4%.

There are low rates of hungry people in developed regions but higher rates in developing regions. From 1990–2016, there were declines in the percentage of hungry people with particularly large decreases in Latin America and Eastern Asia.

The prevalence of underweight children is a major global problem as it is the underlying cause of 45% of deaths in young children and cannot be fully corrected even if sufficient nutrition is provided later. The prevalence of underweight children in 2016 were the following: Southern Asia 27%, Western Africa 20%, Eastern Africa 18%, Southern Africa 11%, Latin America < 10%, and Eastern Asia < 10%. The cause of underweight children is childhood malnutrition, which can be due to suboptimum breastfeeding together with a lack of protein in the diet and deficiencies of vitamin A and zinc. Other nutritional deficiencies (such as protein, iodine, and iron) also impair childhood development and result in physical and mental stunting. The decreases in underweight children under 5 years old between the early 1990s and 2014–2016 generally align with the declines in the percentage of people who are hungry.

At the World Food Summit (WFS) in Rome in 1996, 182 governments committed "to eradicate hunger in all countries, with an immediate view to reducing the number of undernourished people to half their present level no later than 2015." Some countries, but by no means all, have achieved this goal.



Textbox 1C Figure 1 Developed and developing countries.

Birds are a successful class of vertebrates, with billions living from the Arctic to the Antarctic. There are almost 20,000 species of birds across the globe, with a greater number of species of birds than mammals but less than those of fish or insects (birds 18,000; mammals 5,415; fish about 30,000; insects about 1,000,000).

Human population is continuing to expand but, despite the efforts of the global community with the Millennium Development Goals, the number of hungry people remains about the same. Changes in the world's population and the number of hungry people are summarized in Table 1.1.

Earth's human population continues to rise and agricultural production is more than keeping pace with the growth. There are also decreases in the number of people who are hungry. Taken together, agriculture fully met the needs of over 1.5 billion more people in 2015–2017 than 1992–1994. An alternative viewpoint is that the decline of undernourished people is due to the large decrease of the number of very poor and the ability of more people to buy food.

Table 1.1 Changes in the world's population and the number of people getting insufficient nutrients.

	1994	2014
World Population in Billions	5.8	7.5
Number of Hungry People in Millions[2]	1011[1]	795
Percentage of World's Population Who Are Hungry[2]	18.6[1]	10.9
Number in Billions (%) of World's Population Who Are Poor[3]	1.85 (32.5)	0.77 (10.7)
Percentage of Children under 5 Years Old Who Are Underweight	25	14

[1] 1990–1992

[2] Undernourished people receiving caloric intake below the minimum dietary energy requirement.

[3] Living on $1.90 or less per day.

Data from the United Nations (Population Office, FAO, and WHO) and World Bank.

1.2 Domestication and Early Use of Chickens

Chickens were domesticated for food (eggs and meat) and/or for cockfighting. In addition, they were used for religious or ceremonial purposes. Chickens were domesticated from junglefowl (genus: *Gallus*). The species of junglefowl are (1) Red junglefowl (species: *Gallus gallus*) from Southeast Asia (Figure 1.2); (2) Green or Javan junglefowl (*Gallus varius*) from islands of Indonesia; (3) Sri Lankan junglefowl (also known as Ceylon or Lafayette's junglefowl) (*Gallus lafayettii*) from Sri Lanka; and (4) Grey junglefowl (also known as Sommerat's junglefowl) (*Gallus sonneratii*) from the Indian subcontinent.

The principal ancestral stock for the chicken is the Red junglefowl (*Gallus gallus*) (see Figures 1.2 and 1.3). There are thought to have been multiple domestications of junglefowl in Southeast Asia and present day Southeast and Northeast China. These occurred around 10,000 years ago, with chicken bones at archaeological sites in northeast China dated to about 7,500 years ago based on radiocarbon dating. Chickens then spread to the Indian subcontinent, present day Iran and the Fertile Crescent (the areas from present day Egypt through Israel, Jordan, and Palestine to Syria and Iraq), Europe (probably via the Silk Route), and to Africa. In the Indian subcontinent, there was crossing of early domesticated chickens with wild Grey junglefowl, with today's chicken including genetics of both the Red and Grey fowl.

Figure 1.2 Wild Red junglefowl (*Gallus gallus*)—the ancestor of domestic chickens. (Source: Silverfoxz/Shutterstock)

Figure 1.3 Chickens were domesticated from wild Red junglefowl. (Source: andrea lehmkuhl/Shutterstock)

Figure 1.4 Domestic chickens were transported across the Pacific Ocean by the colonizing Polynesians. (Image courtesy of Wikipedia)

Polynesians took chickens along with pigs and Pacific rats as they spread across the islands of the Pacific, even reaching as far as the west coast of South America (Figure 1.4). European colonists took chickens to the Americas. The first recorded chickens were on the island of Cuba in 1495. From their introduction until the advent of large-scale commercial production techniques, chickens were raised as scavenging chickens in backyards and farmyards (Textbox 1E discusses village chickens). There is still considerable potential for the continuation and expansion of this small-scale approach in many communities in developing countries. The addition of egg and meat protein to protein-deficient diets, together with cash income, can make small-scale poultry production very appealing.

Figure 1.5 Wild turkey (*Meleagris gallopavo*)—the ancestor of domestic turkeys. (Source: Tory Kallman/ Shutterstock)

1.3 Domestication of Turkeys, Ducks, and Geese

Turkeys (*Meleagris gallopavo*) were domesticated in the New World by the pre-Columbian civilizations (Aztecs and pre-Aztec peoples) of present-day Mexico and Central America about 2,000 years ago (see Figures 1.5 and 1.6). It is possible that other populations of turkeys (also of different subspecies) were domesticated by the American Indians of the Southwest of what is now the United States of America. The Spanish colonists of Mexico transported domesticated turkeys to Spain as documented in 1501. Later, these were distributed to the Mediterranean countries, to

Figure 1.6 Turkeys were domesticated from wild turkeys. (Source: Richard Wozniak/ Shutterstock)

other countries in Europe, and by the colonists of what became the United States of America. Domesticated turkeys were reared on a small scale by farmers and fanciers particularly in Europe and North America.

Ducks and geese were domesticated multiple times in different places. The two major species of domesticated ducks are Pekin ducks (*Anas platyrhynchos*) and Muscovy ducks (*Cairina moschata*), respectively. Pekin ducks were domesticated at least 3,000 years ago in what is today China (see Figures 1.7 and 1.8) and possibly also in the Fertile Crescent, while Muscovy ducks domesticated in the Northern Andes (present day southern Peru) about 2000 years ago.

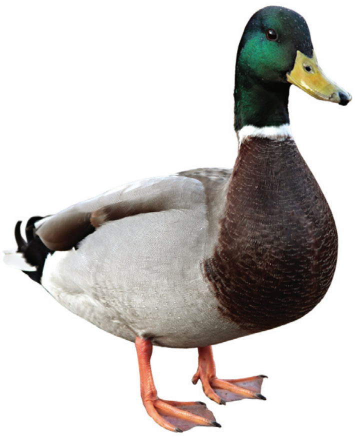


Figure 1.7 Wild mallard ducks (*Anas platyrhynchos*) were the ancestors of domesticated ducks. (Source: Aksenova Natalya/Shutterstock)

Figure 1.8 Ducks were domesticated from wild mallard ducks. (Source: Gumpanat/Shutterstock)

1.4 Global Growth of Poultry and Egg Production

Chicken meat is a major source of meat globally and there have been large increases in the production of chicken and other meat species around the world (Table 1.2). Chicken production today surpasses that of beef, lamb, and goat meat (Table 1.2; Figure 1.9). Production of chicken globally is now only exceeded by production of pork (Table 1.2). China is by far the largest producer of pork with 55 million metric tons produced in 2016. When meat production is ranked across the globe excluding China, production of

Table 1.2 Importance of poultry meat production as indicated by changes in global production of poultry with livestock meats (in million metric tons) over 20 years.

Meat	1996	2006	2016
Pork (pig meat)	79.3	100.8	118.2
Chicken meat	49.1	72.7	107.1
Beef (cattle meat)	53.6	60.5	66.0
Lamb (sheep meat)	7.1	8.4	9.3
Turkey meat	4.3	5.2	6.1
Goat meat	3.2	4.6	5.6
Duck meat	2.2	3.4	4.5
Goose and guinea fowl meat	1.5	2.1	2.5

Data from FAOStat.

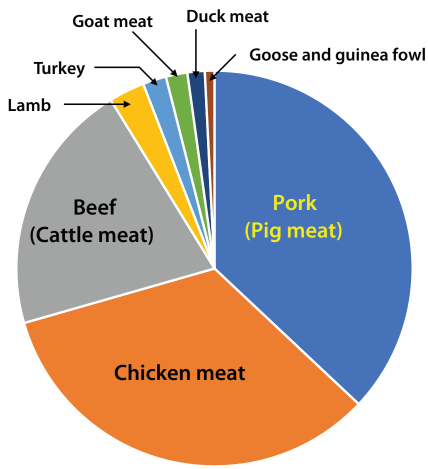


Figure 1.9 Global production of poultry (chicken, turkey, duck, goose, and guinea fowl) compared to other major meats in 2016 (data from FAOStat).

chicken meat exceeds pork, with 93.8 million metric tons of chicken meat produced in 2016 compared to 63.2 million metric tons of pork. Global production of poultry meat more than doubled, increasing by 110% between 1996 and 2016. Total production of poultry meat (chicken, turkey, duck, and goose) rose from 57.1 million metric tons in 1996 to 120.2 million metric tons poultry meat in 2016. While production of pork (pig meat) and beef rose between 1996 and 2016, the increases were markedly smaller than the increases for poultry (49.1% vs. 23.1%, respectively). In comparison, the increase in the human population was 29% between 1996 and 2016 (Table 1.1). Thus, the increase in production of pork and chicken meat greatly exceeded that of human population growth.

The regions with the highest quantities of chicken meat production are the Americas and Asia (see Table 1.3). The largest increases in chicken meat production between 1996 and 2016 were in the Americas (23.8 million metric tons) and Asia (22.2 million metric tons). The greatest percentage increases in production between 1996 and 2016 were in South America (207%), followed by Asia (154%) and Africa (143%).

Table 1.3 Changes in chicken meat production (in million metric tons) in major regions of the world.

Region	1996	2006	2016
Africa	2.3	3.4	5.6
Americas	21.7	33.9	45.5
Asia	14.4	23.5	36.6
Europe	10.2	10.9	18.1
Oceania	0.6	1.0	1.4
North America	12.9	17.3	19.9
South America	6.8	12.8	20.9

Data from FAOStat.

In contrast to the situation with chicken production, turkeys are predominantly produced in the Americas (59% of global production), mostly in North America, and Europe (33% of global production) (Table 1.4). In both North America and Europe, production of turkeys is plateauing, however there is growth of turkey production in both South America and Africa, albeit from low levels (Table 1.4). The production of ducks is focused in Asia, with the region accounting for 84% of global production (Table 1.5).

The top countries for chicken meat production for 2016 are summarized in Table 1.6 (also see Figure 1.10). The three top countries for chicken meat production account for two-fifths of global production. The top chicken-producing countries are the following: (1) the United States, (2) Brazil, and (3) China, accounting for 17%, 13%, and 12% of global production, respectively. There were major increases in the production of chicken meat in the Russian Federation between 2006 and 2016 (156%).

Table 1.4 Changes in turkey meat production (in million metric tons) in major regions of the world.

Region	1996	2006	2016
Africa	0.05	0.09	0.20
Americas	2.8	3.2	3.6
Asia	0.10	0.14	0.16
Europe	1.4	1.8	2.0
North America	2.6	2.7	2.9
South America	0.16	0.42	0.75

Data from FAOStat.

Table 1.5 Changes in duck meat production (in million metric tons) in regions of the world over 20 years.

Region	1996	2006	2016
Africa	0.05	0.08	0.10
Americas	0.09	0.11	0.11
Asia	1.7	2.7	3.8
Europe	0.38	0.39	0.48

Data from FAOStat.

Eggs are a major source of high-quality protein, minerals, and vitamins globally. Production of eggs has increased considerably between 1996 and 2016, increasing by 64% (Table 1.7). Production of milk globally is much higher, 9.4-fold, than that of eggs. However, if we consider the amount of protein produced, the difference is much less (2.3-fold), with global production of protein in cow's milk being 21 million metric tons of protein and in chickens' eggs being 9.3 million metric tons of protein.

Asia produces the most chicken eggs, accounting for almost three-fifths (60%) of global production (Table 1.8).

The top countries for chicken egg production are summarized in Table 1.9. By far, China is at the top, accounting for 36% of global production. There are three groups of countries for chicken egg production

Table 1.6 Top countries for chicken meat production and changes in production between 1994 and 2014.

Ranking in 2016	Country	Production in Million Metric Tons 1996	2006	2016
1	United States	12.2	16.3	18.7
2	Brazil	4.1	8.2	13.9
3	China	6.1	10.2	13.3
4	Russian Federation	0.7	1.6	4.1
5	Mexico	1.3	2.5	3.1
6	India	0.6	1.5	3.4

Data from FAOStat.

Table 1.7 Importance of poultry as indicated by changes in global production of eggs with the other livestock nonmeat product, milk (in million metric tons) over 20 years.

Other Animal Products	1996	2006	2016
Milk (cows)	468	562	659
Milk (buffalo)	57.9	81.2	111
Milk (goat)	11.7	14.7	15.3
Milk (sheep)	8.6	9.3	10.4
Chicken eggs	45.1	57.9	73.9
Other bird eggs (duck and goose)	4.7	4.6	6.9

Data from FAOStat.

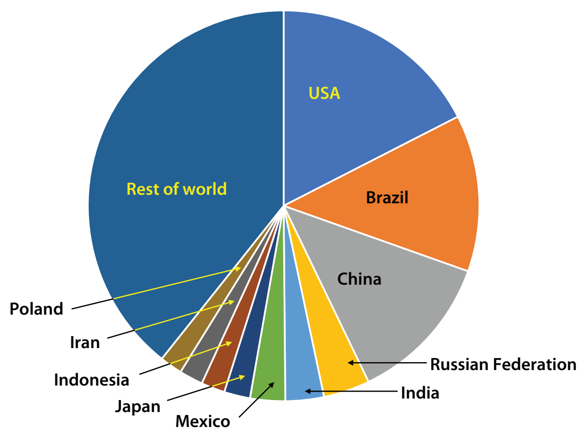


Figure 1.10 Major countries producing chicken meat in 2016 (data from FAOStat).

(Table 1.9; Figure 1.11): (1) Fast-growth countries, including in alphabetical order: China, India, Indonesia, Mexico, Pakistan, the Russian Federation, and Ukraine; (2) moderate-growth countries like the USA and Argentina; and (3) no-growth countries where production has plateaued. Countries that have plateaued are predominantly in Europe (e.g., France, Germany, and the United Kingdom) or developed countries in Asia (Japan and the Republic of Korea).

Duck and geese eggs are also produced and consumed predominantly in Asia (Table 1.8), with China and Thailand producing 5.4 and 0.4 million metric tons of these eggs, respectively. The basis of the increase in poultry and egg production is principally due to the adoption of commercial industrialized production (discussed in Chapter 2) with highly selected meat or egg-laying chickens and also to improvements in the effectiveness of village production. In many devel-

Table 1.8 Changes in egg production (in million metric tons) in regions of the world over 20 years.

	Region	1996	2006	2016
Chicken Eggs	Africa	1.7	2.4	3.2
	Americas	9.1	12.3	14.9
	Asia	24.9	32.9	44.5
	Europe	9.2	10.1	11.0
	Oceania	0.20	0.24	0.32
	North America	4.9	5.8	6.5
	South America	2.6	3.5	4.9
Other Bird Eggs (Ducks and Geese)	Americas	0.04	0.08	0.17
	Asia	4.6	6.6	9.2
	Europe	0.07	0.08	0.09

Data from FAOStat.

oping countries, 80% of chickens are village or indigenous chickens while 20% are commercial chickens (Table 1.10). The village chicken contributes about half the chicken meat but little to egg consumption.

Table 1.9 Top chicken-egg producing countries.

Ranking	Country	Production in Million Metric Tons 1996	2006	2016
1	China	15.9	20.9	26.8
2	Unites States	4.5	5.4	6.0
3	India	1.5	2.8	4.6
4	Mexico	1.2	2.3	2.7
5	Japan	2.6	2.5	2.6
6	Russian Federation	1.8	2.1	2.4
7	Brazil	1.4	1.8	2.3
8	Indonesia	0.6	1.0	1.4

Data from FAOStat.

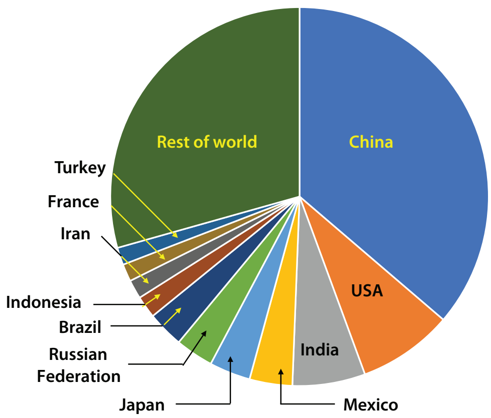


Figure 1.11 Major countries producing chicken eggs in 2016 (data from FAOStat).

Village poultry are predominantly a source of meat. This is due to low egg production, low hatchability, high mortality, high infection by parasites, and low growth rates (discussed in more detail in Textbox 1E). There are a series of approaches (outlined in Table 1.11) that can increase the efficiency of poultry production. This results in both more chicken meat and, progressively, many more eggs to be eaten or sold. Measures to improve the husbandry of village poultry include (1) controlling diseases via vaccination, (2) supplementary feed to provide sufficient key nutrients, (3) shelter to protect from the weather, (4) adding fencing to reduce predation, and (5) reducing parasites (see Table 1.11).

Commercial poultry production moves raising poultry to an entirely new level. It encompasses greatly improved genetics; formulated diets meeting the birds' needs for maintenance, growth, or egg production; control of disease and parasites; and control of the environment of the birds with control of temperature, humidity, and flooring (litter). Intensive poultry production is considered in Chapter 2.

Table 1.10 Comparison of the relative importance of indigenous/village and commercial chicken production in developing countries.

	Indigenous or Village Chickens	Commercial Chickens
National Flock in Developing Countries	80%	20%
Source of Eggs for Consumption	< 10%	> 90%
Source of Chicken Meat by Weight	50	50

Based on Pym et al., 2006; Pym, 2009.

Table 1.11 Recommendations from the United States Agency for International Development on how improved husbandry can affect the efficiency and effectiveness of chicken production.

System	Characteristics	Eggs Hen^{-1} Year^{-1}	Number of Chickens for Meat Consumption	Number of Eggs for Consumption/Sale
Stage 1	Vaccination against Newcastle disease, supplementation feed, shelter.	40–60	4–8	10–20
Stage 2	Same as stage 1 plus further feeding, watering, housing; treatment for parasites, additional vaccinations.	100	10–12	30–50
Stage 3 (Semi-intensive)	Same as stage 2 plus complete diets and improved diets.	160–180	25–30	50–60

TEXTBOX 1D

Points for Discussion

1. Why has poultry production increased? What are the consequences of the increase of global poultry production? Consider in your answer issues such as human nutrition, use of grain, exports of grain, and the environment (poultry waste).
2. Why has the efficiency of poultry production increased? Consider in your answer issues such as poultry genetics, nutrition, disease control, and improved management systems.

TEXTBOX 1E

A Deeper Dive: Indigenous and Village Chickens

In many developing countries, indigenous or village chickens are the most common poultry (FAO, 2016a) (see Textbox 1E Figure 1). Globally, there are about 475 million smallholder farmers with many being poor and hungry (FAO, 2016b). For instance, it is estimated that 80% of households in Thailand raise poultry (Safman, 2009). Indigenous birds comprise about 80% of national flocks in developing countries of Africa and Asia (excluding China and other countries with well-established Western-like commercial egg and broiler production) (Pym et al., 2006; Pym, 2009). These birds forage for nutrients but additionally consume household scraps and minimal quantities of grain (FAO, 2016).

Textbox 1E Figure 1 African village chickens. (Source: Albie Venter/Shutterstock)

In the traditional system, families usually keep between 5 to 20 chickens (FAO, 2008). For instance, in Vietnam most households (8.4 million) have poultry, each having on average 22 chickens (FAO, 2006). The system is low or no input coupled with low output (see Textbox 1E Table 1). Indigenous birds contribute significantly to food security; providing, for instance, 50% of meat consumed in those countries (Pym et al., 2006; Pym, 2009). Surplus males are slaughtered at marketable age (USAID, 2013). The meat produced with the two to three chickens per year is the equivalent of a carcass weight of 1–2 kg per year (FAO, 2008). Chickens have a high social value as gifts to newly married cou-

Textbox 1E Table 1 Comparison of the characteristics of indigenous/village in developing countries in Africa and Asia and commercial chicken production.

	Indigenous or Village Chickens	Commercial Chickens
Eggs produced per year	40–60	> 250
Clutches per year[1]	3.5	Not applicable
Hatchability (Hatching rate) (%)	70–80	> 90
Mortality (first 6 weeks) (%)	65	< 5
Rates of infection with gastrointestinal helminths (%)	~80 (range: 35–100)	< 5
Rates of infestation with ectoparasites (%)	~80	< 5

[1] Between clutches (6–18 eggs per clutch) hens become broody and incubate the eggs.

Based on Permin et al., 1997; Pym et al., 2006; Pym, 2009; Nnadi and George, 2010. Katoch et al., 2012; Hussen et al., 2012.

ples and can be sold either for cash or barter. However, indigenous hens contribute less than 10% of eggs consumed. The reasons for disproportionately low contributions of eggs from indigenous birds are low fecundity (low egg production), high mortality and morbidity, and low growth rate together with the high proportion of eggs being used to hatch and grow for meat (based on Pym et al., 2006; Pym, 2009).

There are little or no disease prevention strategies in indigenous village birds. Viral and bacterial diseases are frequently found and there is marked problems with parasitic infestations. In Iranian village chickens, the incidence of coccidiosis was estimated as 64% (Hadipour et al., 2013). In village poultry, there are high rates of infection with gastrointestinal helminths with, for instance, 72% in Northwest India (Katoch et al., 2012), 89% in Ethiopia (Hussen et al., 2012), and 100% in Tanzania (Permin et al., 1997). Helminths have adverse effects, increasing mortality and depressing growth rates (23.7%) as indicated by the effects of anthelmintic treatment on indigenous growing chickens (Katoch et al., 2012) (see Textbox 1E Table 2). There was marked selection for disease resistance rather than growth or egg production (FAO, 2016). Moreover, these village birds can harbor human and poultry pathogens, being a reservoir for viruses such as highly pathogenic avian influenza viruses.

Textbox 1E Table 2 Effect of helminths on village chickens in northwestern India as indicated by the ability of a broad spectrum anthelmintic (fenbendazole) to improve growth rate, depress mortality, and influence helminth prevalence and load expressed as a percentage of the untreated birds.

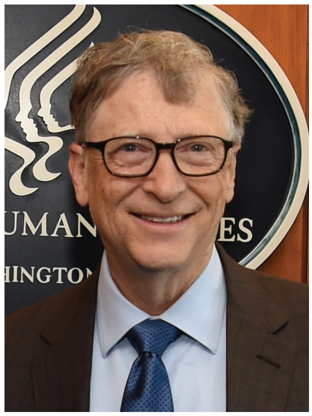
	Growth Rate over 90 days % of Untreated (g Per Day)	Mortality %
Untreated	100 (13.7)	32
Anthelmintic Treated	131 (18.0)	18

Data from Katoch et al., 2012.

TEXTBOX 1F

A Deeper Dive: How Can Poultry Reduce Poverty In The Poorest Countries?

In 2016, Bill Gates recommended raising chickens as a way to overcome poverty for people living on $2 a day (extreme-poverty line). He estimates that raising chickens (starting with 5 hens) would raise income by $1000 per year, even accounting for costs of vaccine against Newcastle disease and feed. In addition, the eggs can reduce childhood malnutrition in the children of the extremely poor. Another advantage in this small-scale poultry production is the empowerment of women. To jump start this, Gates donated 100,000 chickens to be distributed by Heifer International. Gates is not alone. Perrin and colleagues (2000) suggested that the efficiency of poultry production is an effective means of reducing poverty. Improved inputs such as vaccines, enhanced nutrition via supplements, etc., can potentially increase the number of eggs from a scavenger hen from about 30 eggs per year up to 280 eggs per year (seen in commercial layers).



Textbox 1F Figure 1 Bill Gates (b. 1955), an American entrepreneur and one of the founders of Microsoft, is one of the richest people in the world. In the 1990s he and his wife started a charitable organization called the Bill & Melinda Gates Foundation. (Photo Credit: United States Department of Health and Human Services)

TEXTBOX 1G

Points for Discussion

What is the case for commercial poultry production versus traditional poultry production and vice versa? In your answer, consider that traditional poultry production (particularly if upgraded with vaccines, etc.) reduces poverty in rural areas while commercial poultry production reduces the cost of poultry.

1.5 Nutritional and Other Attributes of Poultry Meat and Eggs

There are multiple reasons why more people are consuming eggs and poultry meat. These products are perceived as healthy and nutritious. Table 1.12 summarizes the major nutrient contents of eggs. According to the USDA National Nutrient Database for Standard Reference, eggs and poultry meat have generally low caloric contents and low fat:

- Medium egg (65 calories).
- Large egg (78 calories; 43 calories from 4.8 g fat).
- Extra-large egg (85 calories).
- Jumbo egg (96 calories).
- Grilled chicken breast (100 g or 3.5 ounces) (153 calories; 32 calories from 3.6 g fat).
- Roast duck including skin (100 g or 3.5 ounces) (338 calories; 221 calories from 25.3 g fat or a third of the maximum for a person consuming 2000 calories per day).

Moreover, eggs and poultry have relatively low prices and people enjoy eating them.

How Much Fat Should We Have in Our Diets?

The United States Department of Agriculture and Department of Health and Human Services consider that total fat should not provide more than 30% of caloric intake and saturated fat should not provide more than 10% of caloric intake.

Nutritional Attributes of Eggs

Eggs are an excellent source of protein (Table 1.12), minerals, and vitamins. Eggs are an ideal source of nutrients because the egg was the source of nutrients for the developing chick embryo. Unlike mammals, the chick embryo cannot secure needed nutrients from their mother; rather, it lives in a closed system that must contain all the food needed for development. If even a single nutrient were lacking, the developing embryo would die.

Egg proteins, like other animal products, are easily digested, with digestibilities being 97% for eggs, 95% for milk and dairy products, and 94% for meat. However, plant products have markedly lower digestibilities, with protein in corn flour being 85% digestible whereas proteins in beans are 78% digestible. Egg proteins are of high quality, containing a balanced supply of the 9 amino acids essential to human health:

Table 1.12 Composition of eggs (raw) and chicken (uncooked) with other livestock products (uncooked).[1]

Nutrient	Eggs	Chicken (White)[2]	Ground beef	Pork	Whole milk
Protein (g/100 g)	12.6	23.2	19.4	20.2	3.3
Fat (g/100 g)	9.5	1.6	12.7	4.9	3.7
Carbohydrate (g/100 g)	0.7	0	0	0	4.6
Saturated fatty acids (g/100 g)	3.2	0.4	5.3	1.6	1.8
Monounsaturated fatty acids (g/100 g)	3.7	0.4	4.8	2.1	0.8
Polysaturated fatty acids (g/100 g)	1.9	0.4	0.5	0.5	0.2
Cholesterol (mg/100 g)	372	58	62	64	10
Calcium (mg/100 g)	56	12	12	11	113
Iron (mg/100 g)	1.7	1.0	2	0.9	0.03
Vitamin B_{12} (μg 100/g)	0.9	0.4	2	0.7	0.45

[1] Data from United States Department of Agriculture Agricultural Research Service National Nutrient Database. Shown as g (or mg or μg) per 100 g. For amount in large egg (50 g excluding shell), multiply values by 0.5.
[2] White meat without skin.

Textbox 1H: Proteins

What Is a Protein?

A protein is a chain or chains of 20 different amino acids linked together in a specific order, somewhat like beads on a string. The amino acids can be considered **essential**, **nonessential**, or **conditional**.

- **Essential amino acids**. Either they cannot be synthesized by the body or cannot be produced in sufficient quantities. The nine essential amino acids are histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine.
- **Nonessential amino acids**. Can be synthesized in the body in sufficient quantities. The four nonessential amino acids are alanine, asparagine, aspartic acid, and glutamic acid.
- **Conditional amino acids** or **conditionally essential amino acids**. Cannot be produced in sufficient quantities at conditions such as stress or disease. Conditional amino acids include arginine, cysteine, glutamine, tyrosine, glycine, proline, serine, and ornithine. The latter is not incorporated into proteins but is required in metabolism.

In people, proteins are digested in the stomach and small intestine by enzymes called proteases. The amino acids are absorbed into the blood stream in the small intestine and are used to synthesize the proteins in the body. The quality of a protein can be described by such metrics as its digestibility, biological value, and net protein utilization.

What Is the Digestibility of a Protein?

The digestibility of a protein is the amount digested divided by the total expressed as a percentage.

What Is the Biological Value of a Protein?

The biological value of a protein is the extent that the essential amino acids' composition meets the needs of the person consuming it. The biological value of a protein is reported as a percentage based on the nitrogen used by tissues divided by the nitrogen absorbed.

What Is the Net Protein Utilization of a Protein?

The net protein utilization is a determined percentage based on the nitrogen used by tissues divided by the nitrogen ingested. This metric encompasses digestibility and biological value.

Definition of Recommended Dietary Allowance (RDA)

The Recommended Dietary Allowance (RDA) is defined as the amount of a specific nutrient in the diet, such as protein, that meets the needs of 97.5% of people of the specified age and/or sex.

What Is the Recommended Dietary Allowance (RDA) for Protein?

Both poultry meat and eggs provide key nutrients including high-quality protein. The RDA for protein is 56 g per day for men and 46 g per day for women. The RDA increases by 21 g per day during pregnancy and lactation. There is impaired physical and mental development to children lacking enough protein and particularly high-quality protein in their diet. Along with the developmental issues, there is a higher risk of failure in school for protein-deficient children.

histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The protein quality of eggs is high and is used for evaluating other foods. The biological value of egg proteins is the "gold standard" for quality and is by definition referred to having a value of 100. In comparison, the biological value of milk proteins is 91%, beef is 80%, and wheat protein (gluten) is 64%. The net protein utilization of egg proteins is 94% compared to 82% for milk and 61% for soy protein.

Eggs are a rich source of minerals and vitamins. Minerals in eggs include macrominerals like calcium, iron, and phosphorus, and trace minerals such as iodine and zinc, with iron (Fe^{++}) being essential to the production of red blood cells and iodine essential to thyroid functioning and synthesis of thyroxine. Eggs are also rich in vitamins including vitamin A (retinoids), biotin, thiamin (vitamin B_1), riboflavin (vitamin B_2), niacin (vitamin B_3), pyridoxine (vitamin B_6), vitamin B_{12}, vitamin D, vitamin E, and vitamin K, together with the two essential fatty acids: alpha-linolenic acid (ALA), an omega-3 (ω-3) [18:3n-3] fatty acid and linoleic acid (LA), an omega-6 (ω-6) [18:2n-6] fatty acid. Some vitamins in eggs include (1) vitamin A, which is essential for eye functioning and as a precursor for retinoid acid and other retinols; (2) vitamin D, which is a precursor for a hormone that controls both calcium metabolism and bone development; and (3) vitamin K, which is essential for blood clotting. Biotin, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamine are essential co-factors for metabolism.

A particularly important vitamin in eggs is vitamin B_{12} (see Table 1.12), which is not found in plant-derived foods. Eggs are second only to fish liver oils as a natural source of vitamin D. Essential fatty acids and their derivatives are critical to the development and functioning of the brain and nervous system.

Nutritional Attributes of Poultry Meat

Poultry meat is an excellent source of nutrients, being a great source of high-quality protein (Table 1.12). Globally, poultry meat is predominantly chicken but can also come from turkeys, ducks, and geese. It is economical and quick and easy to prepare and serve. Also, it has a number of desirable nutritional properties.

Nutritionally, people eat poultry meat for its high content of high-quality protein and its low fat content. Turkey and chicken meat are slightly higher in protein and lower in fat than beef and other red meats (see Table 1.12). The proteins are generally readily digested, have a high biological value and are a rich source of all the essential amino acids. The exception to this is collagen, which is found in meat, and is not readily digested. Poultry meat is also a good source of iron.

1.6 Health Consequences of Consuming Poultry Meat and Eggs

People are becoming more and more health and diet-conscious. Consumers perceive the consumption of chicken and turkey meat as being as healthy as eating an egg. The nutrients supplied by eggs and poultry meat provide well-balanced nutrition. For heart-healthy diets the American Heart Association recommends boneless and skinless chicken breasts, turkey breast fabricated into chops and tenderloins, and ground turkey breast. If a little is good, is more better? Parenthetically, the statement is often applied to money. For chicken and turkey meat the answer is most probably yes, but for eggs, probably no.

Are there negative health effects of eating chicken? The simple answer is no. Eating chicken will meet the needs of multiple nutrients. In large clinical studies, chicken consumption has no discernible negative effects of health or mortality. The situation is likely to be the same for consumption of turkey meat. Moreover, rates of mortality have been found to be lower if red meat or processed red meat is substituted by poultry (chicken and turkey meat).

Definitions

Atherosclerosis: The narrowing of the arteries, including coronary arteries (Figure 1.12). This is due to the formation of plaque in the arteries that contains calcium and cholesterol. Plaques reduce the supply of oxygen and nutrients and can lead to heart attacks (myocardial infarction), angina, or strokes and consequently death. About a million people suffer heart attacks each year in the United States.

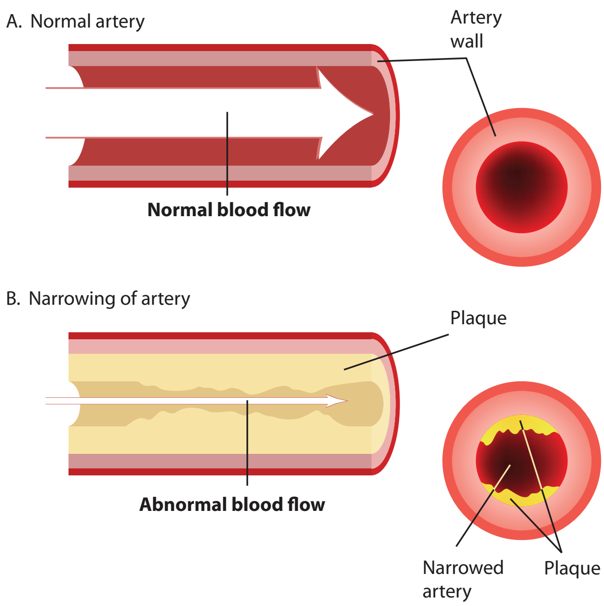


Figure 1.12 Deposition of plaque containing cholesterol and calcium on the walls of arteries reducing blood flow. (Sources: A7880S/Shutterstock; wowow/Shutterstock. Redrawn based on original from National Institute of Health.)

Coronary heart disease or **coronary artery disease**: The narrowing of the coronary arteries that lead to the muscles of the heart. Coronary heart disease is a major cause of death, particularly in developed countries. Risk factors for coronary heart disease include serum cholesterol concentrations (particularly LDL) heredity, hypertension (high blood pressure), diabetes mellitus, smoking, and lack of exercise.

Cholesterol: A four-ring carbon molecule. It is an important compound in the body, for instance, in cell membranes and as the raw material from which steroid hormones are made. It is obtained either from the diet or is made in the liver and is transported principally bound to two proteins, low-density lipoprotein (LDL) cholesterol and high-density lipoprotein (HDL) cholesterol. The cholesterol in LDL can be deposited as plaque and hence is referred to as "bad" cholesterol. In contrast, HDL picks up deposited cholesterol and, hence, is referred to as "good" cholesterol. Causes for high cholesterol and particularly high LDL cholesterol are heredity, lack of exercise, being overweight or obese, stress, age, and diet (high dietary levels of either saturated fatty acids).

Are there negative effects of eating eggs? Consumption of up to an egg per day has no effect on serum concentrations of cholesterol or the incidence of heart attacks, coronary heart disease, or stroke. High consumption of eggs is associated with increases in total LDL cholesterol, which predispose people to coronary heart disease. The American Heart Association recommends using egg substitutes and egg whites, and limiting intake of egg yolks because of both cholesterol and saturated fatty acids.

Another problem is serious food allergies. In an **anaphylactic** reaction, a person can suffer from swelling, hives, and difficulty breathing. Food allergies can be life-threatening in **anaphylactic shock**, where the airway is occluded, preventing breathing.

Occasionally, a child exhibits an allergic sensitivity to eggs. In most cases, the white of the egg is the portion that creates the reaction, and the yolk is generally readily tolerated. In highly sensitive individuals, the diet must be totally devoid of eggs; hence reading food labels is critically important. The presence of egg products in foods with inaccurate labeling has led to the foods being recalled by the USDA.

1.7 Efficiency of Poultry Production

Through the ages, eggs and poultry meat have been a basic food. They are becoming increasingly important in meeting the challenge for feeding the hungry people of the world. Poultry products have proven to be extremely valuable as a source of food for the following reasons:

1. **Poultry convert feed to food efficiently.** Chickens are very efficient in converting plant materials to meat. This is seen in Table 1.13, where the feed efficiency in chickens, turkeys, pigs, and cattle are compared. A similar situation exists for the production of eggs.
2. **Integrated production systems.** For instance, for broiler chicken production, the integrator owns the hatchery producing the chicks, the birds, the feed, the health program, the harvesting, and further processing.
3. **Poultry products are inexpensive.** Poultry meat and eggs are among the "best buys" in the grocery store. This low price is due to efficiency of production and ongoing demand, allowing efficiencies of scale in production.
4. **The short generation time and high fecundity.** Geneticists have been remarkably successful utilizing the short generation time, high fecundity, and scientific selection to improve poultry. For instance, chicken growth is increasing at about 3% per year (see Table 1.14).

Table 1.13 Comparison of feed efficiencies (feed to gain ratios) in meat-producing livestock and poultry.

Species	Feed Efficiencies (Feed to Gain Ratio)
Broiler chicken	1.85 (1:1.85)
Turkey	2.3 (1:2.3)
Pigs	3.0 (1:3.0)
Beef cattle	6–9 (1:6–9)

Table 1.14 Changes in growth rate due to selective breeding based on University of Alberta meat control strains unselected since 1957 and 1978, and a commercial Ross 308 strain from 2005.[1]

	Year	Day	Body Weight (kg)	Feed to Gain
University Study[1]	1957 genetics	56	0.905	2.85
	1978 genetics	56	1.808	2.13
	2005 genetics	56	4.202	1.92
Mean for US Commercial Broiler Chicken Production[2]	1955	70	1.40	3.00
	1975	56	1.71	2.10
	1995	47	2.12	1.95
	2007	48	2.50	1.95
	2017	47	2.81	1.85

[1] University of Alberta Meat Control strains unselected since 1957 and 1978, respectively, and a commercial Ross 308 strain (2005) (data from Zuidhof et al., 2014).

[2] Data from National Chicken Council. While the majority of the increases in performance are due to improved genetics, some are due to improvements in nutrition, health, and management.

5. **Low-cost complete diets.** Nutritionists have developed low-cost diets that meet the needs of the bird.
6. **Animal health assured.** Vaccines, antiparasitics, antibiotics, veterinary care, and stringent biosecurity measures are greatly reducing mortalities and disease associated reducing in performance.
7. **The commercial poultry industry is dynamic.** Because of the short periods required for growing and marketing, the poultry industry can adjust rapidly to a variety of economic factors (e.g., feed availability, numbers of birds on feed, costs, etc.). Other livestock enterprises, notably the cattle industry, need much longer periods to adjust to market changes because of time required for the animals to mature and reproduce.
8. **Some components of poultry feeds are not commonly used for human consumption and are, hence, of a lower cost.** By-products are components of poultry feeds that are fed to poultry. These include animal by-products such as fish meal, blood meal, bone meal; by-products of grain processing for ethanol (these include dried distillers grains, a by-product of producing ethanol from corn by dry milling, the method for 90% of corn in the US), wet distillers grain, and dry high-protein gluten meal; and by-products of producing biodiesel, namely glycerol (for every 10 kg of biodiesel, 1 kg of glycerol is generated) (see sidebar).

Production of Biodiesel

Triglycerides → Fatty acids + Glycerol
↓
Fatty acid esters

9. **Poultry meat and eggs are versatile.** Poultry and eggs are used in many dishes in virtually every cuisine in the world (see Figures 1.13 and 1.14).
10. **Layers provide a continuous source of food.** Unlike meat animals that must be fed for a period of time before a usable product can be attained, layers produce eggs throughout the year. Thus, the layer can produce several times her weight in eggs throughout her life, while the products derived from meat animals are restricted in their final market weight.
11. **Many vegetarians (but not vegans) consume eggs.** In some countries, the eating of meat is taboo by religious precept but the consumption of eggs is acceptable and is a major source of animal protein consumed by the people of these countries.

1.8 Nonfood Uses of Poultry

Chickens are used in scientific research and also have some medical uses. By-products of poultry production such as feathers, used litter, and dry excreta are considered elsewhere (in chapter 11).

Figure 1.13 Chicken is an enjoyable part of our diet that provides high-quality protein. (Source: koss13/Shutterstock)

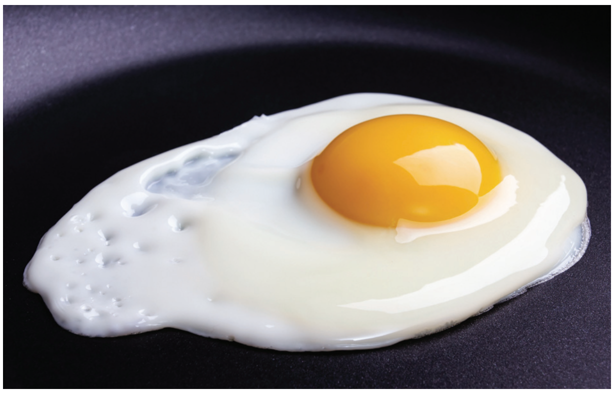


Figure 1.14 An egg is a versatile food that provides high-quality, readily-digestible protein together with minerals such as iron, calcium, and vitamins. (Source: Valentina Proskurina/Shutterstock)

Poultry in Scientific Research

Poultry, especially chickens, have been used extensively as biological tools or models. Chicks have the advantages of being cheap and readily available in large numbers, thus providing for accuracy and precision; have similar genetics; and have a large body of information available. In the case of the latter, there is a wealth of information available on the anatomical, physiological, biochemical, endocrine development, and the underlying molecular and cellular mechanisms of chicks.

Nutrition Studies

Chicks are used as bioassays to demonstrate the need for many of the essential nutrients along with their functions. Much of the very early work on the discovery of vitamins (e.g., biotin, pantothenic acid, riboflavin, thiamin, and vitamin K) used young chickens and/or eggs. The high sensitivity of chicks (particularly their growth) to nutritional deficiencies proved of great value in vitamins, minerals, and amino acids, and to accurately estimate requirements.

Embryonic Development

The chick embryo has been an excellent model for the study of embryonic development. Some of the reasons for the use of the chick embryo by researchers include (1) the availability of a base of information to build upon and of reagents (probes and antisera); (2) the fact that development occurs without influences by the mother, in contrast to the situation in mammals; (3) the ease of experimental manipulations of the embryo *in ovo*; and (4) fewer regulations for experimentation than is the case in studies with mammals.

Toxicology

Both wild birds and poultry may be exposed to toxicants in the environment. The adverse effects of early pesticides, such as DDT, on wild birds were described by Rachel Carson in her 1962 book *Silent Spring*. This book was one of the catalysts for the formation of the environmental movement. Chickens, particularly embryos, have been used as model systems for the effects of toxicants on birds. Researchers have found that the chicken is very sensitive to many toxicants, frequently much more sensitive than other birds.

The chicken embryo has been used extensively as a model for toxicant effects during development. It is particularly useful in examining teratogenic effects (teratogens are chemicals that cause abnormalities of development).

Genomics

Tremendous progress has been made in genomics (the study of the DNA of animals, plants, and microorganisms). Researchers, particularly in North America, Europe, and Asia, sequenced the genome of the chicken. Knowledge of poultry genomes is facilitating programs of genetic improvement and understanding the control of key aspects of metabolism. In addition, it is allowing discovery of the fundamental processes of the evolution.

Definition of Transgenics

Transgenic animals, plants, and microorganisms have received an additional gene or genes (trans-gene or trans-genes) from another individual (often of a different species) or a synthetic gene.

Several approaches that allow modification of the genome of chickens have emerged during the past two decades. One approach introduces site-directed deletions, insertions, and conditional mutations into the genome using primordial germ cells (PGCs). This could potentially create disease resistance or the capability to utilize feedstuffs more efficiently. They have not been implemented due to the negative public perception of genetically modified organisms (GMOs). In contrast, the technology has been used to create chickens producing human monoclonal antibodies (mAbs) by "knocking out" the chicken immunoglobulin genes and replacing them ("knocking in") with their human counterparts. For example, such birds at Crystal Bioscience (an antibody discovery company) are producing human monoclonal antibodies for the therapeutic market.

Behavioral Studies

Birds have been very important in behavioral studies. The pioneering work on imprinting (socialization) was done with goslings (young geese) by the Austrian zoologist Konrad Lorenz. Social order, known as "peck order," was first reported in chickens.

Biomedical Uses of Poultry

There are multiple uses of eggs in human and veterinary medicine, and specifically in the preparation of serums, vaccines, and pharmaceutical products. Bacteriological laboratories can use eggs in the preparation of culture media. Moreover, egg proteins are used as diluents in artificial insemination (diluting semen). Developing chick embryos (embryonated eggs) are used for culturing viruses for the production of vaccines against a long list of human and animal diseases including encephalomyelitis (sleeping sickness),

TEXTBOX 1I

A Deeper Dive: Transgenic Chickens

The production of transgenic chickens is summarized below:

1. Primordial germ cells (PGC) are harvested from chicken embryos at the beginning of development, for instance, from the embryo (18 h of development) or blood (55 h of development).

↓

2. A population of PGC cells is grown *in vitro* in a medium supporting cell multiplication.

↓

3. Genes encoding traits of interest are introduced into PGCs using conventional electroporation technology in combination with "floxed" genes encoding antibiotic resistance and green fluorescent protein (GFP). Addition of antibiotic to the medium eliminates most of the cells in the culture. Only a few correctly modified, PGC-expressing cells survive and are clonally propagated.

↓

4. A population of 10^6 cells is derived from each clone.

↓

5. Approximately 2000 genetically modified cells are injected into recipient embryos to create germline chimeras. Colonization of the germline is estimated by the number of GFP-expressing cells in representative gonads at hatch.

↓

6. Chimeras are reared to sexual maturity. The proportion of sperm cells expressing GFP is estimated by fluorescence-activated cell sorting or PCR. Chimeras with the highest proportion of GFP-expressing (i.e., genetically modified) cells are mated to produce the first generation of heterozygous transgenic offspring.
7. The first generation of heterozygous transgenic offspring carries floxed genes encoding antibiotic resistance and GFP, i.e., genes that are flanked by lox sites. These birds are mated to birds expressing Cre recombinase, an enzyme that excises DNA between lox sites.
8. Offspring from the mating of first generation transgenic birds to Cre birds yields offspring that carry only the desired genetic modification.

Knock-out chickens can be produced (Doran et al., 2016; Dimitrov et al., 2016). These are transgenic chickens with a gene or series of genes no longer functioning, or "knocked out." Mice with specific genes knocked out have been extremely valuable to biomedical researchers.

Transgenic chickens are being used to produce humanized monoclonal antibodies for human therapeutics (in biopharming). This entails the basic scheme above but with the following specifics: (1) The chicken immunoglobulin V (variable) gene is knocked out but replaced by the human V region gene (Collarini et al., 2014; 2015). (2) The transgenic chickens are challenged to produce antibodies (immunized) to a human protein. (3) The chicken produces antibodies to the human protein. (4) The antibody-producing cells are harvested. (5) Cells from a single clone produce identical antibodies to a single part or epitope of the protein. (6) The cells are plated and multiplied. (7) The cells are then transfected to knock out the gene for the chicken constant region of immunoglobulin and replaced with the gene for the immunoglobulin constant region. (8) These cells produce humanized monoclonal antibodies to specific epitopes of the protein of interest.

Chickens are used because the phylogenic distance between a chicken and a human is much greater than from the mouse to the human. This increases the chances of producing antibodies to a human epitope. Also, chicken-produced but humanized monoclonal antibodies recognize both human and mouse epitopes. This is important for testing the efficacy of the antibodies in mice.

measles, smallpox, and so forth. Avian transgenic technology is being used for pharmaceutical applications such as producing human antibodies.

1.9 Projections on the Future of Poultry Production

Chicken Production

Production of chicken is projected to increase globally with broad-based advances in many countries. It is hoped that living standards will continue to improve and that the goals of elimination of poverty will advance. This will only occur with sufficient political will. Moreover, it is important that chicken meat stay affordable. This in turn depends on production. It is predicted that increasingly, chicken will be produced across the world by high-intensity, commercially integrated poultry companies.

Egg Production

Egg production is projected to increase globally with the growth focused in certain regions. Based on FAO data and China's projected 2% compound annual growth rate, the country will produce 34.2 million metric tons of eggs by 2020 and 39 million by 2030. Similarly, large increases (> 50%) in egg production are projected for developing countries such as India, Indonesia, and Pakistan, which experienced marked growth between 2004 and 2014. Egg production in the European Union is likely to be steady, with increasing competition from eggs imported from South America, Russia, and Ukraine.

Low Intensity Production Systems

There is scope for increasing low-intensity poultry production. There is likely to be an increase in niche poultry production (such as organic, Label Rouge, and free range) that supplies poultry for affluent consumers (see Chapter 3 for details). Programs to increase the efficiency of village poultry production should be prioritized by governments, development agencies, and nongovernment organizations such as the Bill & Melinda Gates Foundation. Already, there are improved systems with duck production integrated with aquaculture.

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Commercial Poultry Industry

An Overview

2

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Discuss the development of the American poultry industry.
2. Understand the importance of poultry in North America, focusing on the United States.
3. Understand the changes that have occurred in the poultry industry.
4. Discuss the numbers of broilers, layers, and turkeys raised in the United States.
5. List the top states in egg, broiler, and turkey production.
6. Understand the changes in the development of commercial poultry production.

2.1 Introduction

This chapter will provide an overview of poultry and egg production and consequently an introduction to the more detailed chapters on specific aspects of poultry production, namely Chapters 5–22. The chapter pays particular attention to commercial poultry and egg production in the United States and Canada. The overall themes related to commercial poultry production are equally appropriate for Europe, Asia, Latin America, Africa, Australia, and Oceania.

There have been marked increases in the consumption of poultry meat with the amount of chicken eaten per capita exceeding that of either beef or pork in the United States (see Figure 2.1). Similar increases in chicken consumption are seen globally (see Chapter 1). Consumption of chicken, turkey, and eggs per person is growing slowly in the United States (see Table 2.1). Since the mid-1990s, 44% of all turkey ends up in sandwiches. In 1943, civilian egg consumption was 343 eggs per capita per year. While egg consumption fell after World War II, over the last 30 years it has been growing slowly (see Table 2.1 and Figure 2.2).

Getting eggs and poultry meat from the birds to the consumer involves coordinated efforts from production through marketing. Intensive commercial poultry production is the most integrated livestock in-

Figure 2.1 Fried chicken is one of many ways that chicken is enjoyed. (Source: Settawat Udom/Shutterstock)

Table 2.1 Consumption of poultry products in the US.

	1960	1985	2000	2016
Chicken Meat[1] in lb (kg) Per Capita Per Year	28 (12.7)	53 (24.0)	54.2 (24.6)	62.9 (28.6)
Turkey Meat in lb (kg) Per Capita Per Year	6.3 (2.9)	11.6 (5.3)	13.7 (6.2)	13.2 (6.0)
Number of Eggs Per Capita Per Year	320	249	253	267
Pork in lb (kg) Per Capita Per Year	59.1 (26.8)	52.1 (23.6)	52.1 (23.6)	50.1 (22.8)
Beef in lb (kg) Per Capita Per Year	63.3 (28.7)	79.2 (35.9)	67.8 (30.8)	56.5 (25.7)

[1] Boneless, trimmed (edible) weight.

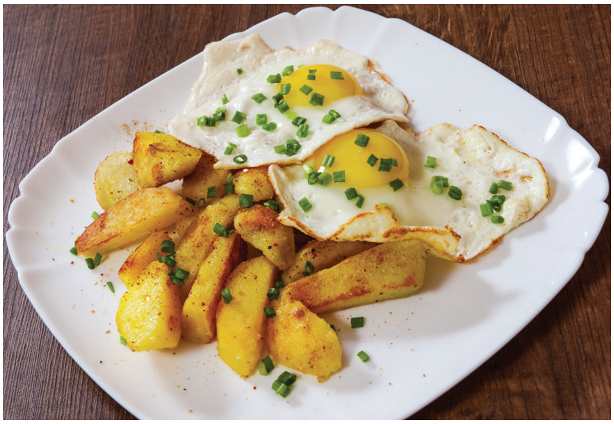

Figure 2.2 Eggs remain a popular breakfast item for many people. (Source: siamionau pavel/Shutterstock)

dustry globally. Companies are organized to control every level of production, from the laying of the egg or the production of the meat through the ultimate promotion and marketing of the finished product.

Primary Breeders

Primary breeders, through multiple selections, develop the grandparent and parent stock for the broiler, turkey, or layer industry (discussed in more detail in Chapter 6). Primary breeders have been responsible for much of the improvement in the efficiency of poultry production.

Commercial Poultry Industry

The **commercial poultry industry** is subdivided into the following components: production of chicken meat, production of turkey meat, and production of eggs. There is also some production of ducks and other birds. According to the USDA's National Agricultural Statistics Service, the direct value of poultry production (US$) in 2016 was $25.9 billion for broiler chickens, $6.18 billion for turkeys, and $6.48 billion for eggs.

US poultry industry groups estimate that the entire poultry industry contributed 1.7 million jobs, $96 billion in wages, $441 billion in economic activity, and $34 billion in government revenue to the US economy in 2016.

Chicken in Metaphors

Chicken as an Indicator of Prosperity: A Chicken for Every Pot

In the past, chicken meat was for special occasions. In the 1928 presidential campaign, a Republican National Committee advertisement was titled "A Chicken for Every Pot," this being a metaphor for economic prosperity. Interestingly, this concept has an earlier origin. King Henry IV of France (1589 to 1610), also known as "Good King Henry," stated, "I want there to be no peasant in my kingdom so poor that he cannot have a chicken in his pot every Sunday" (translated from the original French).

Spring Chicken

Up until the 1920s, chicken meat was a by-product of egg production by dual-purpose backyard flocks. The production of chicken meat resulted from roosters that were seasonally raised for meat. This was the "spring chicken" and eaten along with old hens that were being culled. Describing a woman as "not a spring chicken" is an idiom, arguably misogynistic, meaning that she is old.

2.2 Chicken Meat Production

The chain of events in producing broiler chickens, and hence chicken meat, can be broken down into the following components with integrators controlling multiple stages: primary breeders, broiler breeders, hatcheries, growers, and processors/further processors.

Chicken production is a series of specialized operations. Production can be broken down as follows:

1. **Breeding flocks**. Flocks of broiler breeder chickens provide the eggs necessary to supply industry demand for young meat birds. Fertility and rate of lay are important factors in evaluating breeding stock. The management and other requirements for these birds are exacting.
2. **Hatchery**. Eggs produced by breeders are transported to hatcheries where they are incubated and hatched. They frequently have received critical vaccinations and may be sexed. The newly hatched birds are then transported to grow-out facilities.
3. **Grow-out operations**. Newly hatched birds are first placed into brooding areas and then dispersed throughout the grow-out facility following a management protocol provided by the integrator. The integrator provides the chicks, feed, veterinary care, and harvesting team. The growers usually own the poultry houses and are responsible for care of the chickens. They receive payments based on the weight of chicken going to the processing plant together with quality-related bonuses.
4. **Processing**. Chickens are transported to the processing plant where they are killed and processed to whole chickens or chicken parts. Frequently the chicken meat goes on to further processing, for instance to nuggets or complete meals. There is increasingly further processing of chickens (see Table 2.2).

Table 2.2 Changes in how US consumer's purchase chicken meat.

Year	Whole Chickens (%)	Cut Up as Parts (%)	Further Processed Products (%)
1965	78	19	3
2000	10	44	46
2015	11	40	49

Data from the National Chicken Council.

5. **Further processing**. Poultry meat is now being used in such processed meats as hot dogs, sausages, turkey bacon, cold cuts, buffalo wings, and in fast food restaurants (known in the industry as quick service), for example, McDonald's McNuggets® and ready-to-eat meats.

Turkey production follows a similar pattern as broilers but some producers are independent.

Exports

The poultry industry contributes to US exports. Indeed, the United States is the second largest poultry exporter in the world. The top poultry exporter is Brazil. There is substantial export of poultry, with 6.6 billion pounds (3.0 million metric tons) of chicken meat exported in 2016. That year, the top US export markets were Mexico (1.41 billion lb, or 0.64 million metric tons), Canada (0.36 billion lb, or 0.16 million metric tons), Cuba (0.35 billion lb, or 0.16 million metric tons), Hong Kong (0.33 billion lb, or 0.15 million metric tons), and Taiwan (China) (0.33 billion lb (0.15 million metric tons). Similarly, there are substantial exports of turkey from the United States, with the largest markets for US turkey in 2016 being Mexico, Hong Kong, Japan, Dominican Republic, and Canada, respectively.

2.3 Egg Production

Each morning, millions of Americans routinely eat eggs for breakfast at home or at restaurants because they like them. An Egg McMuffin® is one of the most popular foods at McDonald's, and having breakfast available all day has increased sales even more. Additionally, eggs are used in numerous baked and processed foods to enhance flavor and texture. Egg production can be divided into the following phases:

1. **Market or table egg-producing operations**. Eggs are produced by caged layer hens or in cage-free facilities. The eggs collected in these operations can be cleaned, graded, and packaged on the farm or elsewhere. The former enables marketing eggs directly from the farm to the consumer. The ownership of the egg-producing operations may be a large company or an independent processor.
2. **Broiler breeder eggs** to produce **broiler chicks**.
3. **Replacement pullet production**. Primary breeders provide the genetic stock. Flocks of hens provide the eggs and ultimately replacement pullets. Health, fertility, and rate of lay are important factors in evaluating breeding stock.
4. **Further processing**. Most eggs are processed at the farm or company levels. However, there is an increasing demand for shell-less eggs for the food industry. Eggs (e.g., small) are taken to egg-breaking plants

where the broken eggs are pasteurized and marketed in frozen, liquid, or dry form to such industries as the baking industry and fast food franchises. Table 2.3 shows the increase in consumption of processed eggs in the United States. In a different analysis and according to the American Egg Board, eggs in the United States were treated as follows in 2016: 59% went to retail, 39% were further processed (for food service industries, food manufacturing, retail sales to consumers), and 2.34% were for export.

Table 2.3 Changes in how eggs are purchased in the US (%). Consumers buy eggs either in shells in grocery stores or in products in stores, restaurants, etc.

Year	In-Shell	Processed	Exported
1975	89	11	< 1
2016	57	39	2

Data from the USDA's National Agricultural Statistics Service (NASS).

In the United States, 87% of chicken eggs are consumed (as market or table eggs) and 13% of eggs are incubated. Of the eggs incubated, about 93% are for broiler chicks and 7% are for replacements for egg laying (pullets).

2.4 US Poultry Industry

The US poultry industry is concentrated geographically and in a relatively small number of companies.

Leading Poultry and Egg-Producing States

The 10 leading US states in number of broilers, eggs, and turkeys produced are shown in Tables 2.4–2.6. From these tables, the following deductions can be made:

- From an overall standpoint, the Southeast ranks high as a poultry area.
- Broiler production is focused in a relatively small number of states (see Table 2.4), and in relatively concentrated areas within those states (see Figure 2.3).
- Egg production is now predominantly focused in the Corn Belt states (see Table 2.5). The major reasons for companies to locate in these states are availability of the locally produced corn and soybeans and the elimination of transportation costs. In addition, there is an arable land base for manure disposal.
- Broiler chickens are predominantly produced in states in an arc from Pennsylvania and Delaware through the Eastern Seaboard and the Southern and Gulf States, together with Arkansas. This reflects the low costs of operation including land, labor, and costs for heating buildings; the knowledge base and human capital; and the infrastructure.
- Minnesota and North Carolina have long been the top states for turkey production. Production is also found in other states (e.g., Arkansas), often where broiler chickens are produced or in the Corn Belt (see Table 2.6).

Discussion for Classroom

Why is commercial poultry and egg production located where it is? Consider in your answer issues such as proximity to areas producing major constituents in the feed.

Table 2.4 Top US states for broiler production in 2016.

Ranking	State	Birds (in Billions)	Weight (in Billions) lb (kg)	Ranking for Value Marketed	Value (in Billions)
1	Georgia	1.3	7.9 (3.6)	1	$4.3
2	Alabama	1.1	6.2 (2.8)	3	$3.3
3	Arkansas	1.0	6.2 (2.8)	4	$3.3
4	North Carolina	0.8	6.4 (2.9)	2	$3.5
5	Mississippi	0.7	4.6 (2.1)	5	$2.4
6	Texas	0.6	1.3 (3.8)	6	$2.0
7	Kentucky	0.3	1.8 (0.8)	7	$1.0
8	Maryland	0.3	1.7 (0.8)	8	$0.9
9	Missouri	0.3	1.4 (0.6)	9	$0.8
10	Virginia	0.3	1.5 (0.7)	10	$0.8

Data from USDA National Agricultural Statistics Service.

Table 2.5 Top US states for egg production in 2016.

Ranking	State	Number of Hens (in Millions)	Eggs (in Billions)
1	Iowa	49.2	13.6
2	Ohio	33.3	9.5
3	Indiana	30.5	8.9
4	Pennsylvania	27.2	8.2
5	Texas	20.6	5.6
6	Georgia	18.9	4.9
7	North Carolina	14.5	3.7
8	Arkansas	13.8	3.4
9	Michigan	13.4	4.0
10	California	12.1	3.5

Data from USDA National Agricultural Statistics Service.

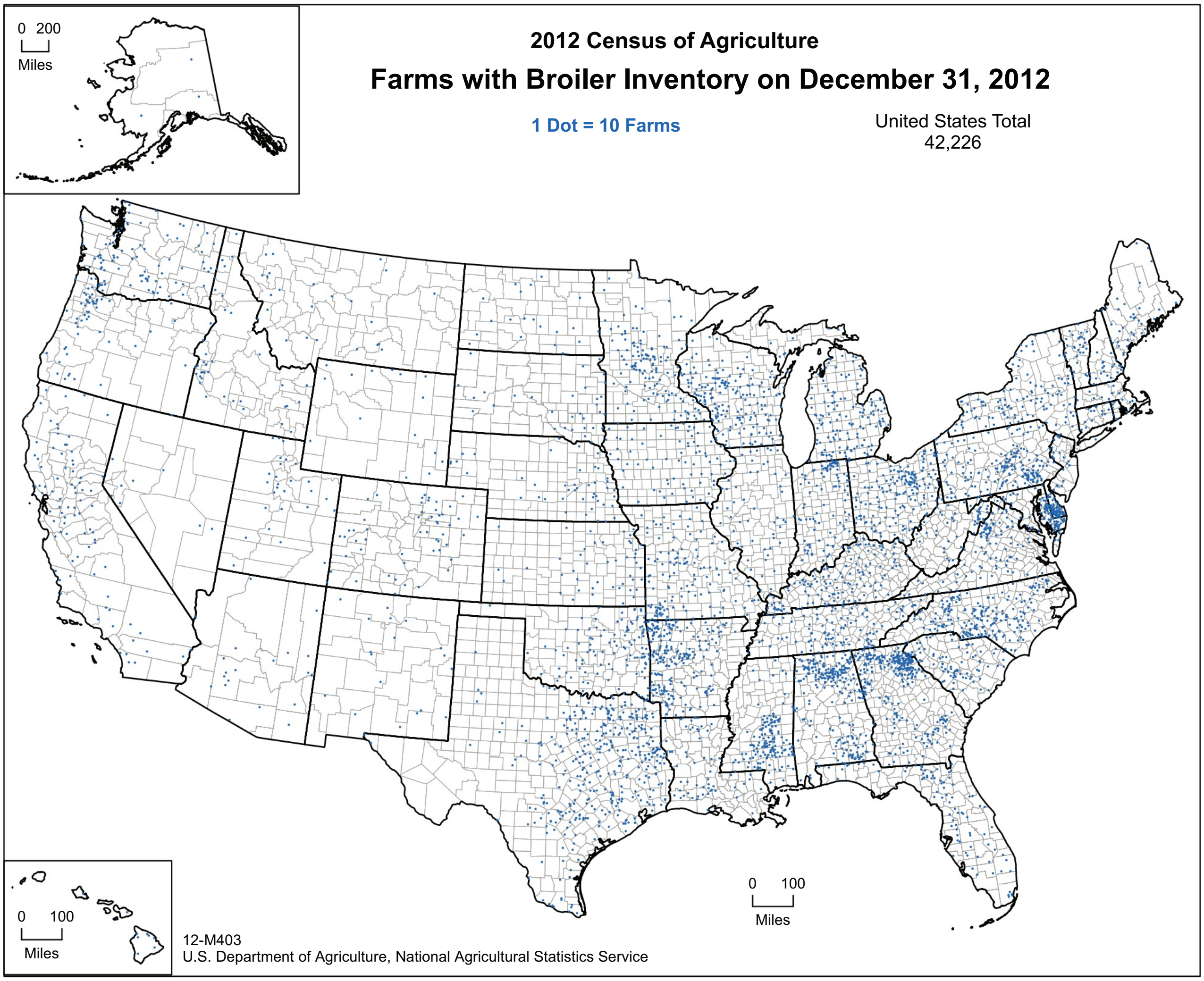

Figure 2.3 Farms with broiler inventory on December 31, 2012. (Source: USDA NASS, 2012 Census of Agriculture)

Table 2.6 Top US states for turkey production in 2016.

Ranking	State	Birds (in Millions)	Weight (In Millions) lb (kg)	Value (in Millions)
1	Minnesota	44.5	1,104 (502)	$912
2	North Carolina	33.5	1,202 (546)	$993
3	Arkansas	26.0	525 (239)	$434
4	Indiana	19.5	759 (345)	$627
5	Missouri	19.2	626 (284)	$527
6	Virginia	17.2	468 (213)	$386
7	Iowa	11.7	461 (210)	$381
7	California	11.4	324 (147)	$267
8	Pennsylvania	7.3	190 (86)	$157
9	Ohio	5.8	237 (108)	$195
10	Michigan	5.4	217 (99)	$179

Data from USDA National Agricultural Statistics Service.

2.5 Poultry Production in Canada

Chickens and turkeys are raised in considerable numbers in Canada. In addition, there is substantial production of eggs. Table 2.7 summarizes poultry and egg production in Canadian provinces. The top three provinces for the aggregate production of chickens, turkeys, and eggs are Ontario, Quebec, and British Columbia. There is significant production in the provinces of Alberta, Manitoba, and Saskatchewan.

2.6 Development and Transformation of the American Poultry Industry

Chickens were brought to the continent by the early European settlers, including the Spanish in present-day Mexico and the English starting the first permanent settlement at Jamestown in 1607. For many years, chickens were cared for by the farmer's wife, who fed them with table scraps and unaccounted-for grain from the

Table 2.7 Comparison of poultry and egg production in Canadian provinces in 2016.

Province/Total	Chickens (in Millions)	Turkeys (in Millions)	Eggs (in Million Dozen Eggs)[1]
Ontario	226.2	9.1	280.9
Quebec	187.7	4.7	140.5
British Columbia	109.0	2.6	90.9
Alberta	67.2	1.9	64.7
Manitoba	33.7	1.5	82.3
Saskatchewan	28.1	0.8	34.6
Maritime Provinces[2]	0	0	44.1
Newfoundland and Labrador	0	0	9.7
Total	706	21.8	748

[1] Includes eggs for hatching.
[2] New Brunswick, Nova Scotia, and Prince Edward Island.
[3] New Brunswick: 22.0 million dozen eggs; Nova Scotia: 18.5 million dozen eggs: and Prince Edward Island: 3.6 million dozen eggs.

Data from Statistics Canada.

crib. Farm flocks supplied the farm families with surplus eggs and meat that were sold in the nearby towns.

Until the 1920s, chicken meat was a by-product of egg production from dual-purpose breeds. The first dedicated meat chickens or broilers were produced in Delaware in 1923 (see Table 2.8). The original dedicated meat chickens were based on Barred Plymouth Rock and New Hampshire breeds. The 1930s saw the start of two of the largest poultry-related companies—Tyson and KFC (see Table 2.8).

In 1948, the Great Atlantic & Pacific Tea Company, together with the USDA, sponsored the "Chicken of Tomorrow" contest, with the goal of developing "superior meat-type chickens" with large breasts, drumsticks, and thighs (see Table 2.8). The winner in the purebred category was the White Plymouth Rocks from Arbor Acres. The overall winner was the Red Cornish crosses from the Vantress Hatchery. These were crossed to become Arbor Acre chickens. The resulting synthetic breeds needed to have white

Table 2.8 Historical changes in US poultry production and marketing.

Year	Event
Before 1920s	Chicken meat production is a by-product of egg production.
1923	First broiler chickens raised in Delaware.
1930	Harland Sanders founded Sanders Court & Café (the forerunner of Kentucky Fried Chicken) in North Corbin, Kentucky.
1930s	John W. Tyson begins transporting chickens from Arkansas to the Midwest.
Before 1940s	Chickens were sold "New York dressed" (with blood and feathers removed but intestines, head, and feet retained).
1942	First processing plant with evisceration (removal of intestines).
1947	Tyson's Feed & Hatchery is incorporated and John Tyson starts raising chickens.
1948	The "Chicken of Tomorrow" contest was held for broilers.
1949	USDA grading of carcasses is introduced.
1952	First Kentucky Fried Chicken located in Salt Lake City, Utah.
1952	Production of specially-bred meat chickens (single-purpose) exceed chickens as by-production of egg industry (using dual-purpose chickens).
1950s	Concept for chicken nuggets developed at Cornell University.
1959	USDA inspection of poultry becomes mandated.
Before 1960s	Separate ownership of feed mills, hatcheries, farms, and processors.
1963	Tyson Foods becomes a public company.
1964	Buffalo wings are first sold in a bar in Buffalo, NY. Since 1977, Buffalo celebrates "Chicken Wing Day" every July 2.
1967	First Chick-fil-A opens. It is now the bestselling chicken restaurant franchise.
1970	At least 90% of broiler production is vertically integrated.
1972	Popeyes Louisiana Kitchen is founded. It now has over 1500 locations in US.
1973	Egg McMuffin® is introduced at McDonald's.
1979	Recipe for Chicken McNuggets® is developed by Tyson.
1983	Chicken McNuggets® are introduced at McDonald's.
1988	McChicken® sandwiches are introduced at McDonald's.
1987	First KFC restaurant opens in China (there are now over 5,000 locations).
1990	First Zaxby's restaurant opens.
1996	Grilled Chicken Deluxe is first introduced (later known as the Chicken McGrill and recently replaced with the Artisan Grilled Chicken sandwich).
1998	USDA requires HAACP (Hazard Analysis and Critical Control Points) at poultry processing plants.
2012	European Union bans battery cages for egg-laying hens.
2015	McDonald's introduces "All Day Breakfast" (with an expanded menu in 2016) with accompanying increase in sales.
2016	McDonald's announces a 10-year plan to use cage-free eggs.
2016	Perdue Farms announces that its chickens will be "antibiotic-free."

plumage because of processor and consumer preferences. Subsequently, there was selective breeding for meat production by breeding companies and this was increasingly effective. Significant events important in the development of the US poultry industry are summarized in Table 2.8, with the development of the supporting infrastructure shown in Table 2.9.

Breeding programs to improve the turkey, preceding those of broiler chickens, were initiated in England in the 1920s. Improved turkeys were imported to the United States and crossed with North American wild turkeys to create the "Broad-Breasted Bronze." It is possible that the Broad-Breasted Bronze are also derived in part from the wild turkey populations (of the subspecies *Meleagris gallopavo silvestris)* on the Eastern seaboard of the United States. In the 1950s, breeders succeeded in developing turkeys with white plumage.

Since World War II, changes in poultry and egg production and processing have outpaced or equaled the developments of other parts of the livestock sector. There have been great increases in the efficiencies of production and the effectiveness of management (summarized in Figure 2.4). The net result is that more products have been made available to consumers at relatively low prices and per capita consumption has soared. This has been due to the following:

1. **Changes in approach.** Poultry production has been clearly segmented into different segments: laying hens producing eggs, broiler chickens producing meat, and turkeys producing meat and frequently adapting approaches from broiler production. The shift to separation of egg and chicken meat production followed moves from dual-purpose breeds to different subsets of chickens selected for either (1) meat-type chickens with high growth rate, more breast muscle (white meat), and superior feed conversion rates, or (2) egg-laying chickens with high egg production and superior feed conversion rates (due in part to reduced body weights).
2. **Changes in breeding.** Standard breeds of chickens were replaced in commercial poultry production by dedicated lines. These were and are developed by the application of modern selective breeding methods. Poultry geneticists used family, as well as individual bird records, to develop lines either high in growth or egg production coupled

Table 2.9 History of the development of academic and other support systems of the US poultry industry.

Year	Event
1862	Morrill Land-Grant Act passed by US Congress, leading to colleges of agriculture at state universities.
1887	Hatch Act passed by US Congress establishing state agricultural experiment stations and agricultural research.
1890	A second Morrill Act is passed and eventually leads to the establishing of historically Black colleges and universities.
1895	Instruction in poultry at Pennsylvania State University.
1908	First publication of the journal *Poultry Science*.
1910	Beltsville Agricultural Research Center is established.
1914	Smith-Lever Agricultural Extension Act passed by US Congress, establishing the Cooperative Extension Service.
1920s	First departments of poultry husbandry, later poultry science, established in US universities.
1928	First publication of the journal *International Review of Poultry Science* (published until 1940).
1935	The USDA National Poultry Improvement Plan (NPIP) is established with the goal to augment poultry quality.
1945	*World's Poultry Science Journal* succeeds the *International Review of Poultry Science*.
1950	First publication of the journal *British Poultry Science*.
1953	USDA's Agricultural Research Service is established.
1954	Plum Island Animal Disease Center is established.
1961	USDA's National Animal Disease Laboratory (NADL) is established.
1965	The "Hispanic-Serving Institution (HSI)" designation began with a goal of expanding educational opportunities for Hispanic students.
1982	Southern Poultry Science Society meetings began, now transformed to the International Poultry Scientific Forum.
1991	First publication of the *Journal of Applied Poultry Research* (JAPR).
1991	Center of Excellence for Poultry Science designated at the University of Arkansas.
1994	Establishment of land-grant colleges for Native Americans.

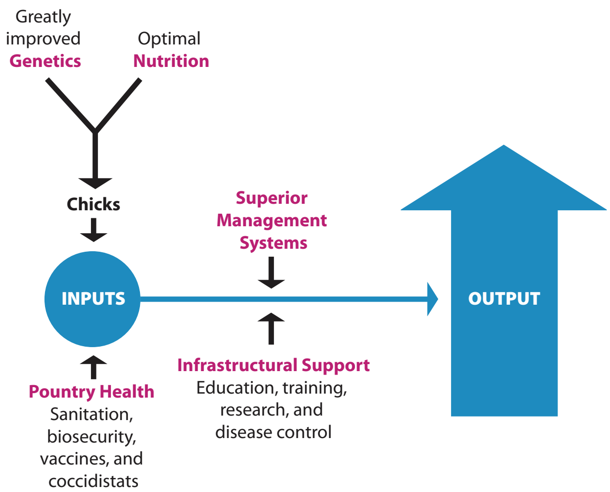

Figure 2.4 Advancements in poultry and egg production/processing have led to greater efficiencies and effectiveness in the industry.

with excellent feed to gain efficiency. Selection results in grandparent lines, and hence parent lines, for broiler meat chickens. Broiler chickens have the advantage not only of selection for superior traits but also for hybrid vigor due to crossing different grandparent lines.

3. **Changes in incubation and sexing.** Incubation used to be done according to nature's way, with a setting hen hovering or sitting over her eggs. Incubations have long been performed at hatcheries, with brooding behavior bred out of commercial chickens (it is still present in multiple noncommercial breeds). "Sexing" chicks (determining sex by inspection of the vent or sex-linked feathering) became widely employed. For egg-type lines, only female chicks are reared; these being as pullets as replacements for layer operations. The male chicks of egg-type lines are euthanized. Hatcheries have become larger in size and fewer in number.
4. **Changes in nutrition.** Poultry feed is formulated to meet the needs of either high growth (broilers) or egg production. Diets always contain optimal levels of macro and trace minerals and vitamins (as determined by research). Diets usually include (1) corn, or maize, as the source for carbohydrate/energy (the price of corn has been maintained at competitive levels by increases in yields in corn production); (2) soybeans as the source of protein supplemented by methionine and lysine such that the requirements of the birds (as determined by research) are met; and (3) other additives such as enzymes, subtherapeutic levels of antibiotics, and botanics.
5. **Changes in production metrics and feed conversion efficiency (FCE).** There has been marked improvements in production metrics and feed conversion ratio of poultry meat and egg productions. In broilers, FCE improved from 4.7 in 1940 to 1.8 in 2018. Eggs improved from 134 eggs per hen in 1940 to 276 eggs per hen in 2015. In 1940, 7.4 pounds (3.4 kg) of feed were needed to produce a dozen eggs; in 2014, it took only 3.6 pounds (1.6 kg).
6. **Changes in disease prevention and control.** Bird mortality has been greatly reduced and poultry health greatly improved with the use of vaccines, coccidiostats, and parasiticides (against helminths and ectoparasites) together with programs of sanitation and biosecurity. Government and universities have also played an invaluable role in improving poultry health. The improvements in poultry disease and control was necessary, but not sufficient, for the expansion and intensification of poultry and egg production.
7. **Changes in management and industry structure.** There are several key trends. Farms have become progressively larger with more birds per farm and work productivity has increased tremendously with automation and advanced management systems. For broiler chicken production, there is vertical integration. The integrator company owns the chickens, supplies the feed, provides veterinary care, and processes the birds. The grower takes care of the growing chickens using their own facilities. The integrator directly produces or contracts for the production of fertilized eggs. The eggs are incubated at integrator-owned hatcheries and vaccination is performed (a similar model can be employed in turkey production). For egg production, eggs can be produced either in company-owned facilities or contacted out.

   In 2012, 96% of the broilers were produced by growers under contract. That represents only 48% of farms producing broiler chickens; the other 52% reflects small-scale producers. It is estimated that about 90% of the eggs are produced under some kind of integrated or contract arrangement. In 2012, growers or contractees made up the following high percentages of other poultry production: turkeys were 69% of production but only 20% of farms; pullets were 63% of production but only 30% of farms.

8. **Changes in labor requirements.** Poultry producers have achieved remarkable efficiency, primarily through increased confinement production and mechanization. In the 1930s to 1940s, 8.5 work hours were needed to produce 100 pounds (45 kg) of chicken meat. Today, less than 0.1 work hour is required.
9. **Changes in processing.** The processing of meat chickens shifted from New York-dressed (feathers and blood removed) and to fully-dressed chickens (with head and intestines, etc., removed) and then marketed chilled on ice or frozen. Today, more are further processed to breasts or breast fillets, wings, thighs, etc., or further processed to ready-to-eat items or complete meals. These changes were designed for convenience, reducing time spent on meal preparation in the kitchen and to add variety to menus. Also, there is a big trend toward chicken items in fast food restaurants.
10. **Changes in chicken consumption.** Per capita chicken consumption in the United States increased due to the low price (see Table 2.10), increased variety of ready to eat meals incorporating chicken, and fast-food chicken menu items.

There has been much less progress reducing the feed or labor requirements for the production of red meats, with the result that poultry producers have achieved a very real economic advantage. In 1910, 88% of the 6.4 million farms in the United States kept chickens with the average size flock being 50 laying hens.

Table 2.10 Changes in the prices of chicken and eggs in the US. While prices have gone up, they have not risen at the rate of inflation. The improvement in the efficiency of production has allowed prices to decline relative to inflation.

	Early 1940s	Mid 1980s	2015/ 2016
Price of Chicken (per lb)	$0.33	$0.90	$1.48
Price of Chicken Adjusted for Inflation (per lb)	$5.56	$1.98	$1.48
Price of Eggs (Per Dozen)	$0.39	$1.10	$1.35
Price of Eggs Adjusted for Inflation (Per Dozen)	$6.50	$2.66	$1.48

Economies of Scale

Economies of scale are when there is greater production with the same fixed costs, such as buildings, land, and capital equipment (per-unit fixed costs decreased); reduced variable costs per unit due to operational efficiencies (e.g., greater productivity of workers, greater scope for automation); and synergies. Economies of scale can be either internal (i.e., within the company) or external (e.g., new technology available across the industry, reduced cost of borrowing, and support infrastructure).

Additional advantages of size include (1) lower costs due to greater purchasing/bargaining power/ bulk buying, (2) marketing costs being spread over more units, (3) administrative overhead costs being spread over more units, (4) more efficient transportation, (5) lower cost of borrowing (i.e., lower interest rates), and (6) having specialized functions that are

TEXTBOX 2A

A Deeper Dive: Changes in the Number of Farms with Laying Hens in the United States

Based on the Census of Agriculture, the number of farms with laying hens has declined in the following manner:

- 1969: 470,832 farms
- 1978: 161,817 farms
- 1987: 89,922 farms
- 1992: 70,623 farms
- 2007: 145,615 farms
- 2012: 198,272 farms

Since 1992, there are over 100,000 more farms with laying hens. However, of the farms with laying hens in 2012, 51,755 farms were primarily poultry and egg operations. Layer farms have continued to get bigger with 434 farms with more than 100,000 layers in 2007 (76.2% of inventory of birds) and 387 farms (76.8% of inventory of birds) in 2012. This contrasts with the average number of laying hens per flock/ farm was about 250 in 1940.

There have been large increases in the number of farms with less than 50 hens in the United States, rising from 125,195 farms to 174,211 farms in 2012. The large increase in the number of farms with less than 50 laying hens reflects greater interest in local small-scale poultry production and backyard poultry.

cost effective, such as having a full-time veterinarian or nutritionist. Companies that are successful in employing economies of scale have a distinct competitive advantage and can be the low-cost supplier. An example of a successful application of economies of scale is Walmart. There are also economies of scope. These are when it is more efficient for a company to produce a range of products and/or there is vertical integration of production.

TEXTBOX 2B

A Deeper Dive: Poultry Production Increases around the World

Predominantly using the same approaches as in the United States and Canada, there are profound increases in poultry production around the world.

Textbox 2B Table 1 Changes in poultry and egg production in Latin America.

	Country and Rank	Production in Million Metric Tons Per Year 1996	2006	2016
Chicken Meat	1. Brazil	4.05	8.16	13.9
	2. Mexico	1.26	2.46	3.08
	3. Argentina	0.75	1.16	1.93
Chicken Eggs	1. Mexico	1.24	2.29	2.72
	2. Brazil	1.37	1.76	2.29
	3. Argentina	0.29	0.42	0.71

Textbox 2B Table 2 Changes in poultry and egg production in Europe.

	Country and Rank	Production in Million Metric Tons 1996	2006	2016
Chicken Meat	**European Union (EU)**			
	1. Poland	0.38	0.82	1.99
	2. United Kingdom[1]	1.13	1.29	1.60
	3. Spain	0.87	1.06	1.23
	4. France	2.66	0.93	1.13
	5. Netherlands	0.67	0.62	1.04
	6. Italy	0.80	0.63	1.02
	7. Germany	0.45	0.61	1.01
	Eastern Europe Not in EU			
	1. Russian Federation	0.68	1.59	4.14
	2. Ukraine	0.22	0.59	1.17
	3. Belarus	0.06	0.15	0.45
Chicken Eggs	**European Union (EU)**			
	1. France	0.99	0.91	1.08
	2. Germany	0.84	0.80	0.81
	3. Spain	0.55	0.83	0.78
	4. Italy	0.74	0.68	0.74
	5. Netherlands	0.60	0.61	0.72
	6. United Kingdom[1]	0.63	0.59	0.72
	Eastern Europe Not in EU			
	1. Russian Federation	1.77	2.10	2.41
	2. Ukraine	0.50	0.82	0.85
	3. Belarus	0.19	0.18	0.21

[1] At the time of this writing the UK is negotiating to leave the EU.

(continued)

Textbox 2B Table 3 Changes in poultry and egg production in Asia.

	Region/Country and Rank	Production in Million Metric Tons 1996	2006	2016
Chicken Meat	**East Asia**			
	1. China	6.14	10.2	13.3
	2. Japan	1.24	1.37	2.35
	3. Republic of Korea	0.40	0.51	0.81
	South Asia			
	1. India	0.62	1.52	2.81
	2. Pakistan	0.35	0.51	1.14
	3. Bangladesh	0.08	0.14	0.19
	South East Asia			
	1. Indonesia	0.93	1.26	2.11
	2. Thailand	0.93	1.07	1.61
	3. Malaysia	0.66	0.90	1.52
	4. Philippines	0.45	0.66	1.20
	Western Asia			
	1. Iran (Islamic Republic of)	0.65	1.36	2.13
	2. Turkey	0.42	0.92	1.88

	Region/Country and Rank	Production in Million Metric Tons 1996	2006	2016
Chicken Eggs	**East Asia**			
	1. China	15.9	20.9	26.8
	2. Japan	2.56	2.49	2.56
	3. Republic of Korea	0.47	0.54	0.71
	South Asia			
	1. India	1.53	2.81	4.56
	2. Pakistan	0.27	0.46	0.76
	3. Bangladesh	0.12	0.18	0.39
	South East Asia			
	1. Indonesia	0.63	1.01	1.43
	2. Malaysia	0.36	0.45	0.83
	3. Thailand	0.52	0.51	0.68
	Western Asia			
	1. Iran (Islamic Republic of)	0.49	0.68	1.19
	2. Turkey	0.61	0.73	1.12

Textbox 2B Table 4 Changes in poultry and egg production in Africa.

	Country and Rank	Production in Million Metric Tons Per Year 1996	2006	2016
Chicken Meat	1. South Africa	0.65	0.97	1.83
	2. Egypt	0.33	0.62	1.05
	3. Morocco	0.23	0.37	0.61
	4. Nigeria	0.32	0.53	0.50
Chicken Eggs	1. Egypt	0.16	0.24	0.51
	2. Nigeria	0.32	0.53	0.50
	3. South Africa	0.28	0.41	0.48
	4. Morocco	0.20	0.24	0.27

Textbox 2B Table 5 Changes in poultry and egg production in Oceania.

	Country	Production in Million Metric Tons Per Year 1996	2006	2016
Chicken Meat	Australia	0.48	0.80	1.18
	New Zealand	0.09	0.15	0.21
Chicken Eggs	Australia	0.14	0.17	0.24
	New Zealand	0.04	0.05	0.06

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Organic, Niche, and Other Poultry with Particular Emphasis on North America and Europe

3

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to do the following:

1. Understand different poultry species and their numbers.
2. Discuss the importance of backyard and pet poultry on commercial poultry production.
3. Understand the requirements of producing organic poultry.
4. Describe the size of organic poultry industry in Europe and North America.
5. Describe the requirements of producing organic poultry.
6. Understand other niche poultry production systems.
7. Discuss the advantages and disadvantages of organic and other niche poultry products.
8. Understand the magnitude of cockfighting globally.
9. Discuss why backyard poultry, pet poultry, and cockfighting are important to commercial poultry production.

3.1 Introduction

This chapter will address poultry in North America that are not part of the conventional commercial production systems. This will encompass organic poultry production (see Figure 3.1); other nonconventional poultry production systems, such as slow-growth, free-range, and Label Rouge; projections of the future of differentiated poultry products; backyard poultry and their implications; and cockfighting and its consequences.

In 2012, according to the American Veterinary Medical Association (AVMA), 3% of US households owned pet birds (parrots, parakeets, etc.), 1% owned poultry (predominantly chickens), 36% owned dogs, and 30% owned cats. According to the United States Census of Agriculture (Ag Census), there are substantial numbers of other poultry (in addition to chickens and turkeys) raised and in the numbers of farms raising them (Table 3.1.).

Figure 3.1 Organic poultry is a growing part of poultry production, particularly in Europe and North America. (Photo Credit: farbled/Shutterstock)

Table 3.1 Relative size of different poultry species in the United States based on inventory in 2012.

Species	Inventory in 2007	Inventory in 2012	Number of farms in 2012
Chickens	1.95×10^9	2.1×10^9	1.7×10^5
Turkeys	1.1×10^8	1.0×10^8	2.0×10^4
Quail	6.3×10^6	2.3×10^6	2.3×10^3
Ducks	4.0×10^6	5.0×10^6	2.1×10^4
Pheasants	2.4×10^6	3.8×10^6	2.3×10^3
Chukars	NA	8.1×10^5	6×10^2
Guineas	NA	4.6×10^5	1.5×10^4
Pigeons	5.3×10^5	4.2×10^5	2.1×10^3
Geese	1.8×10^5	1.1×10^5	1.4×10^4
Hungarian partridge	NA	5.2×10^4	44
Emu	2.8×10^5	1.3×10^4	1.5×10^3
Ostrich	1.4×10^4	6.5×10^3	1.4×10^4
Rhea	NA	1.4×10^3	2.2×10^2

Data from Ag Census.

Myths on Labels

- **"Organic chicken is better for you."** There is not clear evidence for this.
- **"Cage-free broilers" or "Chickens raised cage-free."** No! Meat chickens are not raised in cages.
- **"No hormones."** Hormones are neither approved nor used in poultry production. Also, they are not effective.
- **"Farm-raised chicken."** This is not a USDA-defined category (some would argue that all chickens are farmed-raised). The term "farm-raised" is used in restaurants to refer to (or imply) chicken produced at a local farm.
- **"Natural chicken."** Again, this is not a USDA-defined category. In the United States, ready-to-cook chicken can be marketed as "a natural product" as it does not contain "artificial ingredients, coloring ingredients, or chemical preservatives, and is minimally processed."
- **"Yellow-skinned chicken is better."** No, but it was a great marketing idea. The yellow color comes from the corn the chickens eat together with marigold petals or an extract added into the feed.

3.2 Organic Poultry Production

Production of organic foods, and specifically poultry and eggs, is increasing in North America and Europe (see Tables 3.2 and 3.3, together with Figures 3.2 and 3.3). This is due to consumer perceptions that organically-produced food is healthier, that poultry and other livestock are raised in a more humane manner, and that organic agriculture is better for the environment. As far as marketing poultry and eggs, these perceptions are a reality. It is argued that the tenets of organic agriculture are not based on science but on emotion (see Figure 3.4). Clearly, in some cases the emotion aligns well with accumulated knowledge (the consensus of science) but this is not necessarily always the case. The advantage to the farmer is that the prices obtained can be markedly higher, however this depends on both demand and supply. The costs of organic versus conventional production are higher due to slower growth, poorer feed efficiency, and greater mortality.

The National Organic Program (NOP) in the United States of America is a program started in 2008 and housed within the United States Department of Agriculture (USDA) Agricultural Marketing Service. Farms and processors of organic poultry need to be certified by the USDA and there is regular auditing of detailed records (see Table 3.4). The USDA's National Organic Standards Board (NOSB) defines organic agriculture as "an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity." The overall goal for organic poultry is to assure bird welfare. Specific requirements include provision of clean water, clean litter, being cage-free, and allowing access to the outdoors. Disinfecting chemicals are permitted and vaccination is allowed. Organic poultry must be fed 100% organic feed starting on day 2 of the bird's lives at the latest. Feed components include such organically produced crops as corn, wheat, and soybeans (produced without the use of conventional pesticides, petroleum-based fertilizers, sewage-sludge-based fertilizers, and genetic engineering). Use of feed from genetically modified (GM) crops is specifically banned. Inclusion of animal products (both mammal and bird) in the feed is prohibited but fish meal is allowed. Minerals can be added to the feed, as can synthetic vitamins and synthetic methionine.

The use of antibiotics is prohibited, as are anticoccidial drugs and other parasiticides. While it is often stated that organic poultry must be raised without hormones, all poultry is already hormone-free. Organic poultry must be allowed access to the outside with

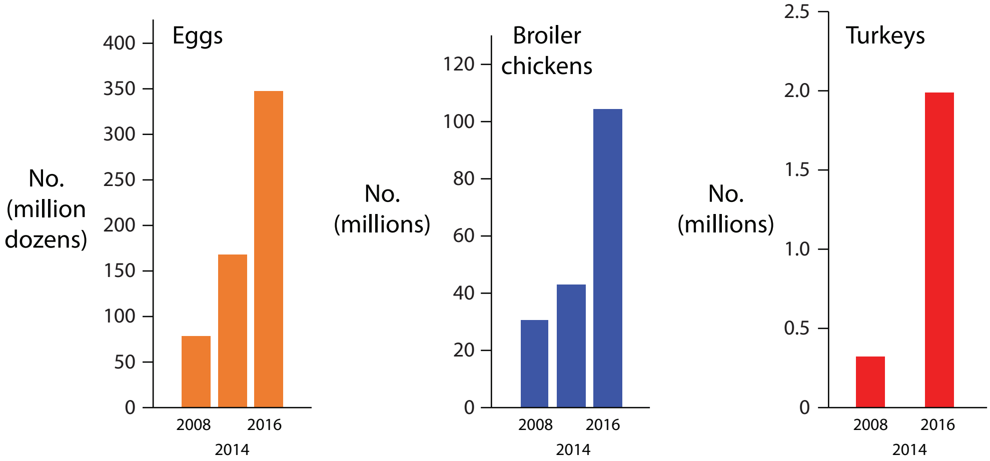

Figure 3.2 Increases in the number (in millions) of organic broiler chickens and number of organic eggs (million dozen) in the US. (Data from USDA)

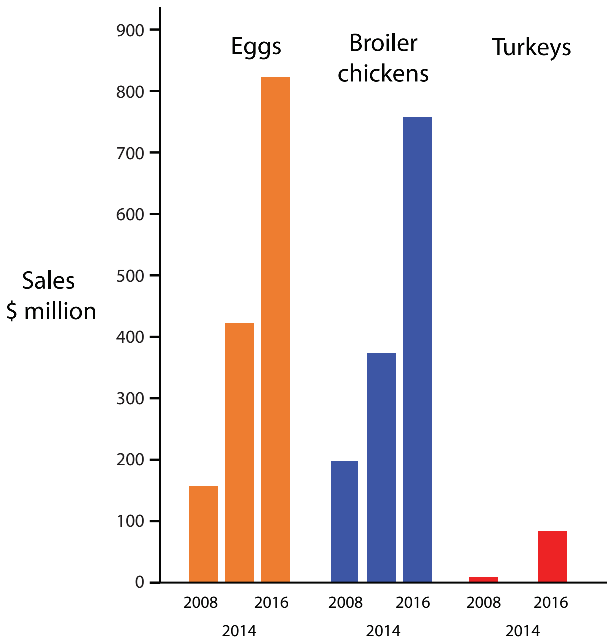

Figure 3.3 Increases in the sales (in millions) of poultry and eggs raised organically in the US. (Data from USDA)

Table 3.2 Comparison of overall organic production and poultry production in the United States in 2008 and 2014.

	2008	2014
Farms (Thousands)	14.5	14
Land (Million Acres)	4.1	3.7
Land (Million Hectare)	1.5	1.5
Eggs (Million Dozen)	80.4	166
Eggs Sales ($ Million)	155	420
Chicken Meat (Number in Millions)	30.6	43.3
Chicken Meat Sales ($ Million)	196	372

Data from USDA National Agricultural Statistics Service.

Table 3.3 Requirements for organic poultry production in the United States.

List #	Requirement
1	Certified organic feed [nongenetically modified organisms (non-GMO) crops produced without chemical fertilizers].
2	Housing with sufficient space to allow the expression of natural behaviors.
3	No synthetic amino acids[1] and no animal products.
4	Access to the outdoors.
5	Antibiotics, drugs, and synthetic parasiticides (for both endoparasites and ectoparasites) are not permitted.
6	Approved vaccines are allowed including Marek's disease vaccine and Newcastle disease vaccine.
7	Comprehensive recordkeeping allowing an audit trail.
8	Production practices that do not contaminate either soil or water or use sewage sludge.
9	No ionizing radiation pre or post processing.

[1] For exception see Table 3.4.

shelter proved and production should be environmentally benign, with care taken to prevent soil erosion and contamination of watersheds.

Figure 3.4 A rooster on an organic farm. (Photo Credit: Stephen Kirkpatrick/USDA Natural Resource Conservation Service)

According to the National Agricultural Statistics Service (a branch of the USDA), organic agriculture in the US in 2016 had $7.6 billion of sales, 14,217 certified organic farms, and 5.0 million certified acres (2.02 million hectares). In 2016, eggs accounted for $816 million in sales, chicken meat (broilers) for $750 million, and turkeys for $83 million.

The top states for organic broiler chicken production are Pennsylvania, with 51% of US production, and California, with 38% of US production. Pennsylvania is also the top producer of organic turkey, with 52% of US production. Indiana is the top US producer of other poultry (e.g., ducks) at 22% of US production. The top three organic egg producers in the US are Pennsylvania (15% of US production), California (13%), and Missouri (9%).

In the European Union, there are analogous requirements for organic poultry production; again, with organic feed required along with rigorous record-

Table 3.4 Summary of requirements for organic production of poultry and eggs.

	USDA's National Organic Program (NOP)
Requirements	"Farmers are exempt from certification because they sell less than $5,000 worth of organic products per year" but they must comply with the regulations.
	All other organic producers must (1) apply for certification including organic system plan (including documentation of management procedures and a manure management plan) and map of the farm, (2) have organic handlers/processors (also needing to certified), (3) have on-site (on farm) inspection and certification by a USDA-accredited certifying agent that determines that the applicant is complying with regulations, and (4) have recordkeeping, such as the source of chicks, poults, ducklings, etc. (these can be from conventional sources), and feed sources with receipts and labels.
Requirements for Organic Poultry Production	Organic poultry and eggs must come from birds that have been raised as organic—with organic feed—from day 2 of life and have a balanced diet.
	Feed ingredients must be certified organic (produced without the use of either synthetic fertilizers or biosolids from municipal waste or sewage sludge). Also prohibited are conventional pesticides (insecticides, herbicides, and fungicides), as specified on the National List of Allowed and Prohibited Substances.
	Allowed feed ingredients include DL-Methionine, DL-Methionine-hydroxy analog, and DL-Methionine-hydroxy analog calcium; calcium carbonate and calcium chloride or oyster shells; magnesium sulfate; trace minerals; vitamins; and prebiotics and probiotics.
	Clean cool drinking water, direct sunlight, and fresh air.
	Preventative measures such as vaccines (e.g., to Marek's disease, Newcastle disease, and infectious bronchitis) and other veterinary biologics; biosecurity; sanitation; composting mortalities; and predator control.
	Access to the outdoors and sufficient space to allow for exercise.
Prohibited Feed Ingredients and Practices	Antibiotics, ionophores, and parasiticides (except for breeding stock).
	Arsenicals for single-celled parasite control in starter diets.
	Animal (livestock and poultry) by-products in the feed.
	De-beaking and toe trimming.

Source: Baier, 2015.

keeping. Requirements include that organic and conventional poultry cannot be in the same farm. At least 20% of feed should be self-produced on the farm or cooperatively in the region with organic producers. Fishmeal is permitted if coming from sustainable fish. Synthetic amino acids are prohibited but synthetic vitamins are allowed. Space requirements are a maximum of 10 birds, or 21 kg live weight, per square meter for meat chickens and 6 birds per square meter for laying hens in a poultry house. The minimum age for marketing is 81 days. The corollary to this is that slow-growth lines are used. As in the United States, use of antibiotics and anticoccidial drugs is not allowed. In the United Kingdom, there are additional requirements on top of the EU's requirements for organic food to receive the Soil Association's organic symbol. This includes the birds being completely free-range with access to pasture via more pop holes (free-range poultry is discussed below). The size of the flocks is lower (500 per house for layers and meat chickens and 250 for turkeys) but can be increased to 2000 if welfare metrics are met. Beak tipping is prohibited and perches must be available for laying hens and pullets.

TEXTBOX 3A

Points for Discussion

1. What are the justifications of the USDA establishing its organic production system?
2. Does organic food contain pesticides?
3. What would be the consequence of a large shift to organic production from conventional production?
4. Are organic poultry products worth (or not worth) the money?

TEXTBOX 3B

A Deeper Dive: Organic Agriculture

Organic agriculture is supported by the International Federation of Organic Agricultural Movements (IFOAM); representing 105 countries. Production of organic food and specifically poultry is increasing globally, particularly in North America and Europe. Organic production of meat chickens has been associated with markedly slower growth of the birds, higher feed intake and consequently much poorer feed efficiency, and greater effects on the environment in terms of GHG emissions and eutrophication potential (Leinonen et al., 2012) (see Textbox 3B Table 1).

There is evidence for increased incidence of pathogens in organic poultry. For instance, *Campylobacter* were isolated from all (100%) organic flocks tested in Denmark, compared to 37% of conventional flocks (Heuer et al., 2001). On the other hand, the prevalence of *Salmonella*, based on fecal samples, was greater in conventional than organic flocks with similar differences in feed samples (Alali et al., 2010). Risks of foodborne *Toxoplasma gondii* from commercial broiler chickens are very low, however the risks from organic chicken are much higher due to presence of *T. gondii* (prevalence 17%–100% in the United States). This is thought to be due to their access to pasture (Dubey, 2010; Jones and Dubey, 2012).

Textbox 3B Table 1 Comparison of the growth rates, feed consumption, and impact on the environment of organic and free-range poultry production systems with conventional poultry production.

	Conventional	Free Range	Organic
Average Final Age (d)	39	58	73
Average Final Weight (kg)	1.95	2.06	2.17
Average Feed Intake (kg/bird)	3.36	4.50	5.75
Average Mortality (%)	3.50	4.70	4.10
Bedding (kg per bird)	0.16	0.22	0.32
GHG (kg of CO_2 Equivalent Per kg of Edible Carcass Weight)	4.40	5.20	5.70
Eutrophication Potential (g of PO_4 Equivalent Per kg of Edible Carcass Weight)	20.30	24.30	48.80

Data from Leinonen et al., 2012.

From 2002–2015, the land being dedicated for organic production in the European Union (EU) increased by 6% per year from 5.7 million hectares to 11.1 million hectares. Most organic producers are in France and Germany. About 1% of poultry and eggs are produced organically in the EU, however, over a third of the eggs produced in France are organic. It is projected that the growth of organic production for poultry and eggs in Europe will continue.

There are disadvantages of organic poultry. For instance, there is evidence for a higher incidence of foodborne disease-causing organisms in organic poultry with, for instance, *Campylobacter* and *Toxoplasma gondii* found in some organic flocks. Moreover, with the slower growth and higher feed efficiency, organic poultry production has a greater impact on the environment, producing more greenhouse gases and excreta. The nitrate and phosphate in the excreta can lead to eutrophication of waterways.

3.3. Free-Range Poultry

There have been marked increases in the number of poultry raised in free-range conditions, with a particularly large increase in the number of free-range laying hens in Europe. There are many proponents of free-range poultry including the Humane Society of the United States (HSUS) and many organic enthusiasts. The strength of the commitment of some to free-range production can be seen from the following. Robert Hadad of the HSUS considered that restricting outdoor access for poultry "based on the fears of disease, is generally unfounded." In contrast, with the threat of the spread of avian influenza and as a precautionary measure, the Department for Environment, Food and Rural Affairs in the United Kingdom required all chickens, turkeys, and ducks be kept indoors irrespective of the size of operation (i.e., including back garden birds).

Organic poultry are free-range but not all free-range poultry are organic. The only requirement for free-range poultry is access to the outdoors, for instance, on pastures (see Figures 3.5 and 3.6). The advantage of free-range is the perception that free-range poultry are healthier and "happier," with the chickens being able to peck at vegetation, soil, and invertebrates, such as worms. This perception is based at least in part to people anthropomorphizing chickens (thinking of them as human). Most of us enjoy being outdoors in nice weather doing things like walking, running, playing games, barbecuing, or picnicking. It's easy for us to reason that chickens should like to be outside. However, do we enjoy the outdoors as much when the weather is adverse?

Free-range production is associated with issues including decreased growth rates, increased mortality, increased cannibalism, increased losses due to predators, increased presence of pathogenic bacteria and parasites, increased risk of spreading foodborne disease organisms to people, and increased risk of spreading poultry diseases. It is easy to see diseases spread to and from wild birds, including waterfowl. Moreover, poultry with access to the outdoors can potentially spread pathogens as aerosols. With the increase of outdoor production systems, including pastures for

Figure 3.5 Free-range chickens on a pasture with their chicken tractors in Salisbury, Maryland. (Photo Credit: USDA NCRS)

Figure 3.6 Chickens on pasture in Victoria, Australia. (Photo Credit: FiledIMAGE/Shutterstock)

TEXTBOX 3C

A Deeper Dive: Free-Range Poultry

Studies using N-15 (a nonradioactive isotope of nitrogen) enrichment provide strong evidence that free-range chickens are consuming significant quantities of growing vegetation such as grass, and soil invertebrates such as earthworms and insects (Coletta et al., 2012). The latter provide an additional source of protein. Free-range chicken meat is darker and yellower but there is no discernible effect on protein or fatty acids (Stadig et al., 2016). Impacts of raising chickens with access to the outside (free-range) are summarized in Textbox 3B Table 1.

Evidence for the Issues with Free-Range Poultry Production

1. **Decreased growth rates**. Free-range, slow-growing female chickens had lower growth rates (terminal body weight decreased by 12%), poorer feed efficiency (12%), but no difference in carcass yield (Wang et al., 2009). Similarly, free-range chickens had lower growth rates in another study (Stadig et al., 2016). In contrast, Fanatico and colleagues (2009) reported improved growth of slow-growing chickens with access to the outdoors.
2. **Increased mortality and cannibalism**: Housing laying hens under free-range conditions is associated with increases in mortality, both parasitic and bacterial diseases, and of cannibalism compared to conventional housing (Fossum et al., 2009). Similarly, meat chickens with access to the outdoors had greater mortalities (Fanatico et al., 2009).
3. **Increased losses due to predators**. In a study of laying hens raised as organic with access to the outdoors in the Netherlands, 40% of flocks had losses from predation (Bestman and Wagenaar, 2014). However, losses of broiler chickens due to predation can be decreased by environmental enrichment with either sorghum or olive trees. Environmental enrichment with olive trees reduces mortality (from 8.6% to 4.4%) and foot pad dermatitis (class 2 from 18.2% to 9.0%) (Dal Bosco et al., 2014).
4. **Increased presence of pathogenic bacteria and parasites**. In the Netherlands, 25% of organic flocks do not receive wormers in their first 50 weeks (Bestman and Wagenaar, 2014). An outbreak of histomoniasis in free-range laying hens was associated with infection with *Brachyspira*-like bacteria. There was also an 11% decrease in egg production and a 6% increase in mortality (Esquenet et al., 2003).
5. **Increases risk of spreading foodborne disease organisms to people**. Substantial numbers of processed chickens raised under free-range conditions were reported to be contaminated with *Salmonella* with equivalent or higher rates than conventional chickens (Bailey and Cosby, 2005). The risks of foodborne *Toxoplasma gondii* are much higher from free-range chicken (prevalence 17% to 100% in the US) than for commercial broiler chickens (< 0.5%) (Dubey, 2010; Jones and Dubey, 2012).
6. **Increased risk of spreading poultry diseases**. There are distinct risks of poultry pathogens being spread to other flocks, including commercial poultry. This can occur via infection by wild birds, through clothing or vehicles, by failures of biosecurity, and at meets of poultry enthusiasts.

poultry in Western Europe and North America, there is an increased possibility of transmission of helminth parasites. According to the National Chicken Council, less than 1% of chickens in the United States are raised under free-range conditions.

3.4 Other Nonconventional Poultry Production Systems

Slow-Growth Chickens

Slow-growth chickens are being increasingly sold. This is particularly the case in Europe with the Label Rouge chickens (discussed below) and increasingly in the United States, albeit starting at a low level. Some advocates claim that the fast growth in broiler chickens is unnatural. Rejoinders are to complain "What is natural?" and to point out that no domestic animal is natural. Whole Foods, a large premium grocery store, announced in 2016 that it wants its suppliers to switch to raising slow-growth-rate chickens. Their plan is expected to take eight years and will represent about 3 percent of the country's broilers.

Whole Foods also subscribes to the Global Animal Partnership's 5-Step® Animal Welfare Rating system:

- Step 1: No cages, no crates, no crowding.
- Step 2: Enriched environment.
- Step 3: Enhanced outdoor access.
- Step 4: Pasture centered.
- Step 5: Animal centered, no physical alterations.
- Step 5+: Animal centered, entire life on same farm.

Textbox 3D

Points for Discussion: Slow-Growth-Rate Chickens

Whole Foods claims that slow-growth-rate chickens are healthier and the meat is tastier. Similar claims are made for Freedom Ranger and Red Ranger lines of chickens (see Textbox 3D Figure 1) in the United States and for the Label Rouge in France.

1. How reliable are these claims?
2. Is there evidence for the claims?
3. What sorts of evidence should be there to make such claims?
4. Should claims be science-based?
5. How should science-based evidence be produced?
6. What is "conflict of interest" and how does this impact funded research?

Textbox 3D Figure 1 Red Ranger chickens at Welp Hatchery in Bancroft, Iowa.

An example of slow-growing chickens in the United States is the Crystal Lakes "Free Ranger." Like the Label Rouge chickens, the Free Ranger must be pasture-raised. The system also prohibits antibiotics, coccidiostats, and animal products in the feed.

Slow-growth breeds of chickens used in the United States include the Freedom Ranger, Heritage (cross of standard breeds), Naked Neck, Red Ranger, and the SASSO Red (primarily a breed for Label Rouge). These breeds take over 40% longer to reach market weight. In consequence, they are much less efficient as they eat more feed, use facilities longer, and require more labor. On the other hand, they are used by top chefs and in trendy restaurants.

Label Rouge Poultry

Label Rouge poultry is thought by some to have a superior eating quality. In France, about one-third of chickens purchased are Label Rouge. The European Union defines Label Rouge as "traditional free-range poultry." The system to produce Label Rouge chickens requires small producers, low growth lines of chickens, and pasture feeding. There is third-party certification. Individual farms are limited to four poultry houses with a maximal size of 400 square meters (4,304 square feet). Free-range conditions are required after six weeks of age with pasture feeding using portable field pens. Within the portable poultry houses the birds must have a maximal stocking density of 11 birds per square meter. Other specifications include the following:

- Slow growing lines, such as from the poultry breeding companies SASSO and Hubbard.
- Low-protein and low-calorie diet with no animal or fishmeal.
- Synthetic amino acids and coccidiostats are allowed.
- Minimum age at market is 81 days with dressed weight of 2.2 kg.
- Air-chilled.
- Sold as fresh within 9 days of slaughter.

There are also Label Rouge standards for turkey, guinea fowl, geese, ducks, and capons (see sidebar below).

Definition

A **capon** is a surgically castrated chicken. Because the testes are located in the abdominal cavity, surgery has to open the abdominal wall.

TEXTBOX 3E

A Deeper Dive: Label Rouge

The effects of the Label Rouge system have been examined. Textbox 3E Table 1 summarizes a study comparing slow and fast-growing chickens with access to and no access to the outdoors. Label Rouge conditions are associated with much slower growth and poorer feed: gain efficiencies (Lewis et al., 1997; Fanatico et al., 2005a; b; 2006) (see Textbox 3B Table 1). The study showed that breast weight was also markedly lower (see Textbox 3B Table 1). There were differences between visible indices of the meat of the Label Rouge birds (slow growth and access to pasture). The color was more yellow and less red, indicating an intake of different colored compounds from the pasture.

Textbox 3E Table 1 Comparison of production parameters and meat characteristics of chickens of either slow or fast-growing lines with access and no access to the outdoors.

Parameter	Slow Indoor	Slow Outdoor	Fast Indoor	Fast Outdoor
Age at slaughter	81	81	53	53
Weight gain (kg)	2.11	2.25	2.51	2.46
F:G	3.58	3.37	2.13	2.17
Breast weight	275	297	412	437
Meat Quality				
Dry matter (%)	27.4	27.6	27.8	28.9
Texture (force N)	10.4	10.4	9.9	8.4
Color (red)	3.7	2.4	4.4	4.3
Color (yellow)	2.2	6.2	2.2	3.1
Sensory Characteristics of Cooked Meat				
Texture	6.23	5.89	6.23	6.13
Tenderness	6.37	6.01	6.36	6.13
Juiciness	2.51	2.32	2.71	2.49

Data from Lewis et al., 1997.

3.5 PROJECTIONS ON THE FUTURE OF ORGANIC AND NICHE POULTRY PRODUCTION AND DIFFERENTIATED PRODUCTS

Predicting the Future

Trying to predict the future is like trying to drive down a country road with no lights while looking out the back window.

—Peter Drucker (1909–2005),
American management consultant

Given the caveat that it is not possible to predict the future, it is readily possible to describe trends:

1. Consumption of organic foods is increasing (see Figures 3.2 and 3.3) and will continue to rise.
2. Consumption of slow-growth chickens is beginning to increase and will continue to do so.
3. There will be a greater use of niche poultry by restaurants as a differentiating feature.
4. There will be a greater adoption of the mind-set used by niche poultry producers by other parts of the poultry industry.

3.6 BACKYARD POULTRY AND THEIR IMPLICATIONS

Backyard poultry, particularly chickens and ducks, are gaining in popularity (see Figure 3.7):

- 6.5% of households in rural areas of the Southern United States raise poultry.
- 4% of homes on one acre or more in metropolitan areas in the United States raise chickens.
- 1% of households in cities in the United States raise chickens, with 4% planning to raise them.

The increase in backyard poultry is due to the likability of chickens. Backyard flocks are used for eggs, meat, showing, and—illegally—for cockfighting. Disease control and biosecurity is frequently minimal at best for backyard poultry in both developed and developing countries. The lack of disease control and biosecurity represents a threat to commercial poultry production with backyard poultry acting as a potential reservoir for pathogens. In addition, the presence of pathogens that cause diseases, such as *Salmonella*, can threaten public health.

Figure 3.7 Backyard chickens are popular, with about one million US households having pet poultry. (Photo Credit: Kaichankava Larysa/Shutterstock)

When keeping backyard chickens it is important to assure the chickens have suitable nutrition, fencing to prevent predation, clean areas (by removing manure and disposing of it in a way that prevents the spread of pathogens and assures environmental quality), are vaccinated, and that ectoparasites and endoparasites are controlled (e.g., by using anthelmintics).

Public Health Risks of Backyard Poultry

According to the Centers for Disease Control (CDC), backyard poultry (chickens and ducks) are gaining in popularity but there are accompanying public health risks, particularly to children. This is due to the presence of *Salmonella* and other human pathogens in poultry excreta and on their feathers, feet, and beaks. The pathogens can also be spread onto people's shoes and clothes. To address these risks, the CDC has a number of recommendations:

- Children under five years old should not handle poultry except when under adult supervision. Note that many children and adults unconsciously touch their mouths even after handling poultry.
- Everyone should wash their hands thoroughly after handling poultry, soil that may be contaminated with pathogens, and dirty clothes.
- Do not eat or drink in poultry areas.
- Do not let poultry inside the house or into areas where food and beverages are consumed.
- Equipment that comes into contact with poultry or their excreta should be washed outside the house.

TEXTBOX 3F

A Deeper Dive: The Popularity of Backyard Poultry

Backyard chickens are growing in popularity. In rural areas, it is estimated that 6.5% of residences in the Southern United States have poultry flocks, both chickens and game birds (Garber et al., 2007). This is similar to the estimate that in the metro areas of Denver, Los Angeles, Miami, and New York City, 4% of single-family homes on 1 acre (0.40 hectare) or more own chickens (USDA, 2013). There have been increases in the number of people in US urban and suburban areas with backyard chickens (Linares and Nixon, 2011). The USDA reports that in the same metro areas as above, about 1% of households have chickens, with 4% planning to own them. This urban ownership of chickens is said to be related to chickens being "likable" and providing eggs (Linares and Nixon, 2011). This could be partly due to the "eat local" movement, with the eggs perceived as more healthy and nutritious (Linares and Nixon, 2011; Blecha and Leitner, 2013; United States Department of Agriculture, 2013).

Textbox 3F Figure 1 Backyard chickens have grown in popularity due, in part, to the likability of chickens. (Source: greenair/Shutterstock)

TEXTBOX 3G

A Deeper Dive: Problems with Backyard Chickens

Problems with backyard chickens include the following:

1. **Biosecurity.**
   - The chickens are in contact with wild birds and can exchange pathogens.
   - Backyard chickens can be a reservoir of avian pathogens, potentially highly pathogenic avian influenza H5N1 (HPAI H5N1) and parasites.
   - Poultry diseases can be spread to commercial poultry by owners of backyard chickens and their vehicles.
2. **Inadequate programs for poultry health** include a lack of vaccination, with Marek's disease being a major cause of mortalities (Mete et al., 2013); inadequate control of parasites; and inadequate veterinary care.
3. **The risk of spreading zoonotic diseases** (e.g., salmonellosis and campylobacteriosis) to the owners and their families and hence to the community.
4. **Inadequate animal welfare** due to predators, including foxes, raccoons, and coyotes; cannibalism due to lack of beak trimming; poor nutrition; increased disease with mortalities frequently due to infectious diseases; and effects of adverse weather.
5. **Impact on neighbors** (noise from roosters, odor, flies, rodents, and attracting predators that can attack dogs, cats, and potentially children) and oversight.
6. **Regulations and city ordinances.** Are hens and/or roosters allowed in a specific locality?

3.7 Cockfighting and Its Consequences

Raising and maintaining chickens for cockfighting is a facet of small-scale poultry production found in much of the world. Accompanying the actual cockfighting is betting on who will be the winner. Cockfighting is illegal in many countries, including the United States and the United Kingdom. However, by forcing the activity underground, the need for secrecy increases the risk that poultry pathogens will be spread and presents potentially serious consequences for the commercial poultry industry.

TEXTBOX 3H

Implications of Cockfighting

Cockfighting has been practiced for over 3,000 years in the Indian subcontinent and the Near East. It was popular with the Ancient Greeks and Romans around the Mediterranean Sea (see Textbox 3H Figure 1). American leaders who enjoyed cockfighting include George Washington, Thomas Jefferson, Andrew Jackson, and Abraham Lincoln (US National Parks Service, 2014).

While cockfighting is illegal in many countries, it does not mean that it is not occurring. The magnitude of illegal cockfighting occurring in the United States can be seen from a single coordinated series of raids in New York in 2014 where over 3,000 chickens were rescued from a single cockfighting ring (Antenucci and Fonrouge, 2014). In Puerto Rico cockfighting is legal and regulated by the Cockfighting Affairs Commission. It is a popular attraction. It is estimated that there are 200,000 fighting birds and 190,000 fights at 128 cock pits (gallerias) attended by 1.3 million people annually (US National Parks Service, 2014). The economic impact of cockfighting in Southeast Asia can be

Textbox 3H Figure 1 A mosaic depicting a cockfight that was discovered in a ruined house in Pompeii, dating to around the first century AD. (Photo Credit: Wikimedia Commons/Carole Raddato)

(continued)

gleaned from the price of a champion gamecock in Thailand at US$2500 (Sipress, 2005). Moreover, estimates of the number of gamecocks in Thailand are 3 to 8 million (Safman, 2009) (see Textbox 3H Figure 2).

Textbox 3H Figure 2 Cockfighting in Thailand can be a very lucrative business, with some larger host stadiums making hundreds of thousands of dollars off bets in a single day. (Source: MuellekJosef/Shutterstock)

Similar "fighting-cock owners" exist in large numbers in Indonesia (Forster, 2009).

The intimate relationship between humans and gamecocks increases the risk of transmission of zoonotic diseases (Sipress, 2005). Moreover, movement of gamecocks increases the risks of transmission of diseases to and between poultry (Sipress, 2005). During a serious outbreak of avian influenza in Thailand, there were programs of depopulation of all poultry within a 5-kilometer radius of the site of identified AI, including gamecocks. Checkpoints on roads were established within a 50-km radius of the outbreak (Safman, 2009). Gamecock owners pushed for a program of vaccination against AI but it was not approved due to the importance of poultry exports (~$0.8 billion) and the resistance of markets (e.g., the EU and Japan) to accept vaccinated products. Inspection of gamecocks and a "passport" allowing movement allowed the continuance of cockfighting (Safman, 2009).

The risk of pathogen transmission from gamecocks is likely to have increased in the United States following the banning of cockfighting. This is because public health and animal health professionals have difficulty contacting people involved in the illegal activity. Moreover, surreptitious fights and gamecock markets are obviously unregulated but provide opportunities for disease transmission.

Cockfighting and American University Athletic Teams

Some universities have athletic teams linked to cockfighting, including the Gamecocks of the University of South Carolina and the Blue Hens of the University of Delaware.

Figure 3.8 The mascot of the University of Delaware Blue Hens. (Photo Credit: Aspen Photo/Shutterstock)

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4

Poultry Biology

CHAPTER SECTIONS

OBJECTIVES

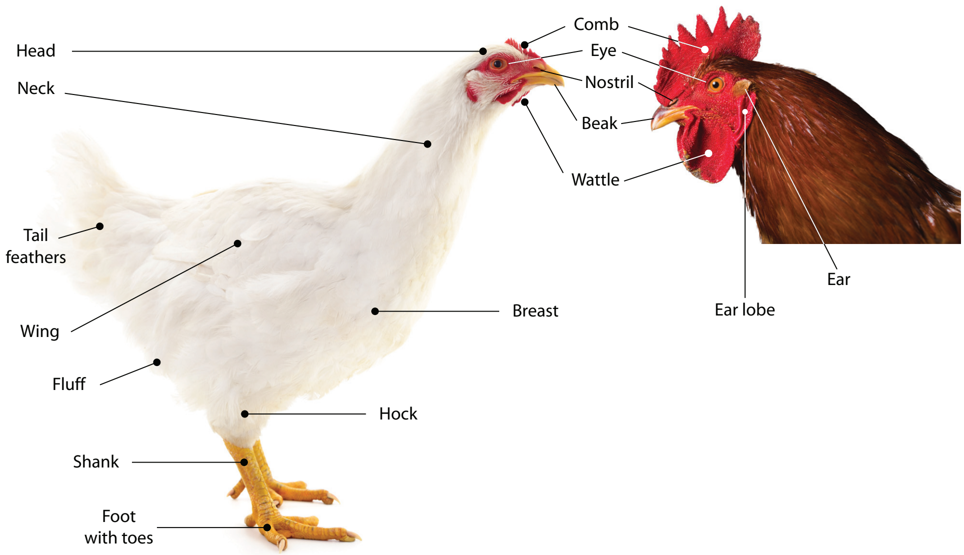
After studying this chapter, you should be able to:

1. List the evolutionary ancestors of birds.
2. List the classification scheme for chickens and turkeys.
3. List the major parts and functions of the bird integument.
4. List the three major muscle types.
5. List and describe the major skeletal muscle cell types found in birds.
6. Describe the path of blood as it flows around the bird's body.
7. List the major blood cell types and give their function.
8. Describe the major differences in the respiratory systems of birds and mammals.
9. List the parts of the bird's digestive system and give the function of each part.
10. List eight major functions of the liver.
11. Describe the digestion and absorption of carbohydrate, fat, and protein.
12. Describe the absorption of vitamins and minerals.
13. List the parts of the large intestine and the functions of each part.
14. Describe the kidney and list the major nitrogen excretory compound.
15. Describe male reproduction.
16. Describe female reproduction.
17. List factors affecting egg size.
18. Identify parts of an egg.
19. List common egg abnormalities.
20. Define clutch size.

4.1 Introduction

It is important for poultry scientists, people in the poultry industry, and educated animal scientists to know the right terminology for the anatomy of chickens and other poultry species. In addition, it is desirable to have an overall mastery of the internal anatomy and physiology of chickens.

Chickens are readily characterized in the following ways: bipedal (two legs), each foot has three functioning toes (metatarsus) and one accessory toe, two wings, a feather-covered body, a neck, and a head with two eyes, two nostrils, two ear openings, and on the top, the comb and the wattles above and under the head, respectively. Figure 4.1 summarizes the external anatomy of chickens with the appropriate terminology.



A. White hen. (Source: Galyna Syngalevska/ Shutterstock.com)

B. Head of a rooster. (Source: Pazyuk/ Shutterstock.com)

Figure 4.1 External anatomy of the chicken with terminology.

Figure 4.2 shows the anatomy of the foot of a chicken. The internal anatomy is covered in sections below.

If poultry are to achieve maximum bird performance, poultry scientists should have a basic understanding of the bird's structure and of how the systems of their bodies function. Through knowledge of the biology of chickens and other poultry species, it may be possible to manipulate the body functions of the birds to attain maximum production. One example of how the knowledge of physiology has been adapted to poultry production is the manipulation of light (day length) to promote egg production. Additionally, the structure of the digestive tract differs from that of ruminants (e.g., sheep, cattle) or of nonruminant mammals (e.g., horse, pig); hence, feeds and management procedures must be designed accordingly.

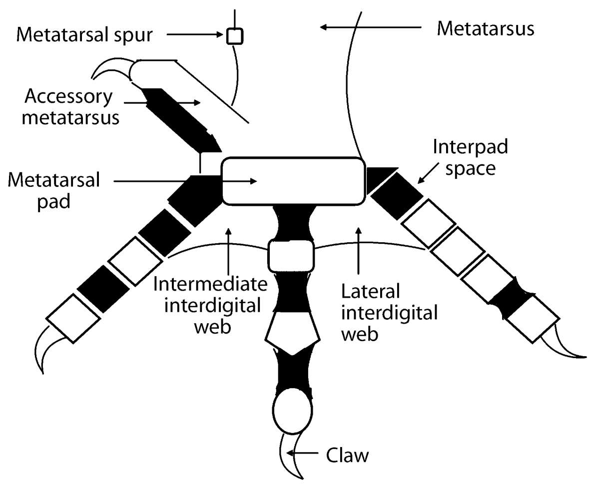


Figure 4.2 Anatomy of a chicken foot. (Note: Some breeds of chickens have five toes. These breeds include the Dorking, Faverolle, Houden, Sultan, and Non-Bearded Silkie Bantam.)

4.2 Evolution and Classification of Birds

From an evolutionary viewpoint, birds can be viewed as warm-blooded, feathered, flying reptiles. Birds evolved from a reptilian group called archosaurs during the Mesozoic Era (see Figure 4.3 and Table 4.1). This is based on fossil evidence together with comparisons of the genomes in existing birds and reptiles. The last common ancestor of birds and crocodiles (living archosaurs) lived about 240 million years ago in the Triassic Period. Within the archosaurs, birds evolved from bipedal dinosaurs that had feathers. Fossils of a primitive bird, *Archaeopteryx*, were first discovered in 1860 in rocks of the late Jurassic period and dated to about 150 million years ago (Figure 4.4). *Archaeopteryx* had wings, feathers, but also teeth. Based on its anatomy, it is thought that *Archaeopteryx* could fly. There are also fossils of earlier archosaurs with feathers; hence, it seems that birds evolved from feathered bipedal reptiles in the Jurassic period.

The major groups of birds living today diverged from each other during the Cretaceous period (see Figure 4.5). Birds that can be classified as *Neoornithes*, or

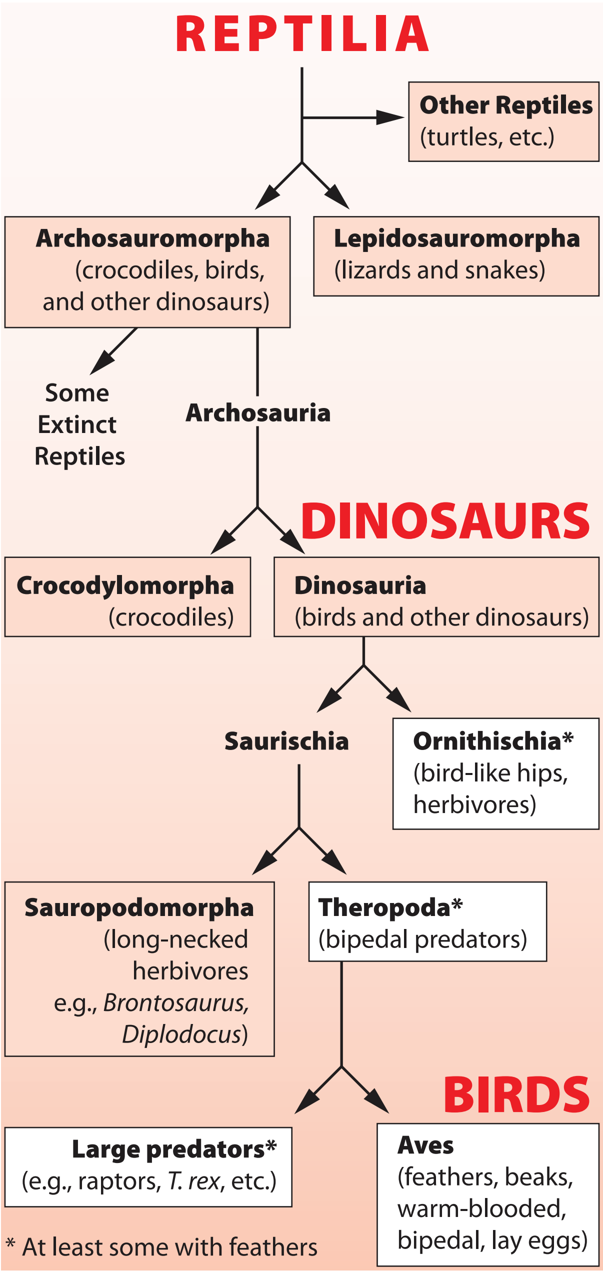


Figure 4.3 Evolution of birds from reptiles (class *Reptilia*) and specifically from dinosaurs.

modern birds, are thought to have originated about 97 million years ago. At the end of the Cretaceous period, dinosaurs and many other species died out. Fossils of these species are found in rocks up to the Cretaceous–Paleogene (K–Pg) boundary. The mass extinction of so many species has been linked to a large meteor hitting the earth. While some species of birds within the *Neoornithes* survived the K–Pg, all others went extinct.

Modern birds (class Aves, subclass *Neornithes* or new birds) are classified as members of two infraclasses: *Paleognathae* (ancient-jawed) and *Neognathae* (new-jawed). Paleognathous birds include the ratites: ostriches, emus, rhea, kiwis, and tinamous. In addition, there are extinct birds such as the multiple species of moa from New Zealand and the elephant bird from Madagascar. The vast majority of birds alive today are classified as neognathous (in the infraclass *Neognathae*) in two superorders (see Figure 4.5):

- *Galloanserae*, containing the orders *Anseriformes* (ducks and geese) and *Galliformes* (chickens, turkeys, and pheasants).

Table 4.1 Divisions of geological time showing when birds evolved.

Era	Period	Epoch	Beginning in Years
Paleozoic	Cambrian	—	542.0 MYA
	Ordovician	—	488.3 MYA
	Silurian	—	443.7 MYA
	Devonian	—	416.0 MYA
	Carboniferous	—	359.2 MYA
	Permian (P)	—	299.0 MYA
Mesozoic	Triassic (T)	—	251.0 MYA
	Jurassic (J)	—	199.6 MYA (First birds)
	Cretaceous (K)	—	145.5 MYA (First modern birds and major divergence)
Cenozoic	Paleogene (Pg)[1]	Paleocene	65.5 MYA
		Eocene	55.8 MYA
		Oligocene	33.9 MYA
	Neogene[1]	Miocene	23.0 MYA
		Pliocene	5.33 MYA
	Quaternary	Pleistocene	1.80 MYA
		Holocene[1]	11,500 years ago

[1] The Paleogene and Neogene are considered together as the Tertiary Period.

Based on US Geological Survey Fact Sheet 2007–2015.

Figure 4.4 Fossil of *Archaeopteryx*, an archaic species of birds with wings, feathers, but also teeth. The fossil pictured here is from the Fukui Prefectural Dinosaur Museum in Katsuyama, Fukui Prefecture, Japan. (Source: Akkharat Jarusilawong/Shutterstock)

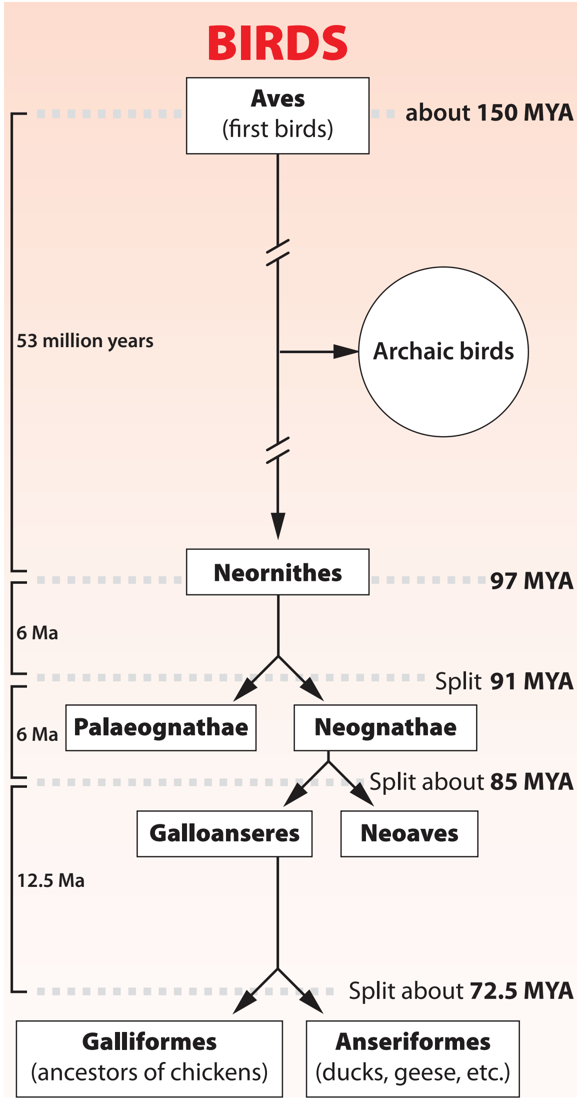


Figure 4.5 Evolution of major groups of birds.

- *Neoaves*, consisting of all the other living birds, such as eagles, flamingos, heron, owls, penguins, pigeons, parrots, starlings, and their ancestors.

Classification

Domestic chickens are in the species *Gallus gallus* or junglefowl (see Figure 1.2) but were sometimes referred to as *Gallus domesticus*. Chickens and turkeys are classified as follows:

- Phylum: *Chordata*
- Subphylum: *Vertebrata*
- Class: *Aves*
- Subclass: *Neornithes*
- Infraclass: *Neognathae*
- Superorder: *Galloanserae*
- Order: *Galliformes*
- Family: *Phasianidae* (pheasants, grouse, chickens, turkeys)
- Species: *Gallus gallus* (chicken); *Meleagris gallopavo* (turkey)

Other galliform birds are in the following families:

- Family *Odontophoridae* (New World quail, e.g., bobwhite quail)
- Family *Numididae* (guinea fowl)

TEXTBOX 4A

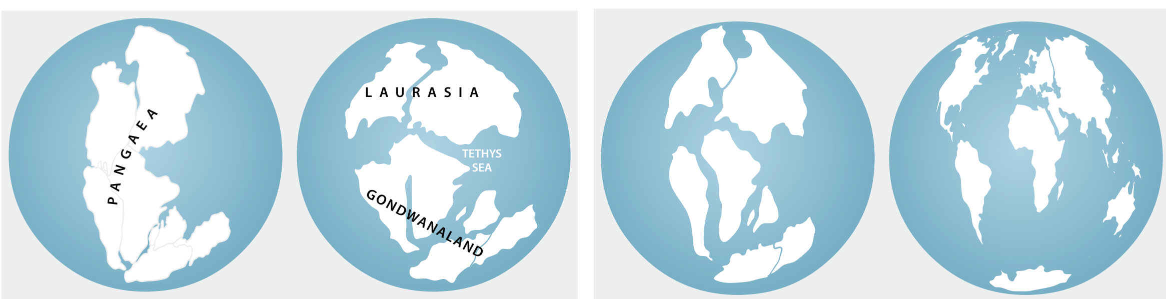
A Deeper Dive: The Evolution, Classification, and Relationships of Birds

Class Aves (existing birds) are divided into taxa:

- Subclass: *Neornithes* (modern birds)
  - Infraclass *Paleognathae* (ratites such as emu, ostrich, rhea, kiwi, together with closely related birds)
  - Infraclass *Neognathae*
  - Superorder *Neoaves* including such taxa as the following orders:
    - — *Apodiformes* (humming birds and swifts)
    - — *Columbiformes* (pigeons and doves)
    - — *Cuculiformes* (cuckoos)
    - — Land birds grouping, e.g., the following Orders:
      - – *Passeriformes* (song birds such as cardinal and sparrows),
      - – *Psittaciformes* (parrots),
      - – *Falconiformes* (falcons),
      - – *Accipitriformes* (eagles, hawks, vultures),
      - – *Strigiformes* (owls)
      - – *Piciformes* (woodpeckers)
    - — *Phoenicopteriformes* (flamingos)
    - — Water birds grouping containing, for instance, the Orders:
      - – *Pelecaniformes* (pelicans, cormorants, ibises)
      - – *Procellariiformes* (petrels and albatrosses)
      - – *Sphenisciformes* (penguins)
      - – *Ciconiiformes* (storks)
      - – *Gaviiformes* (loons)
  - Superorder *Galloanserae*
    - — Order *Anseriformes* (ducks and geese)
    - — Order *Galliformes*
      - – Superfamily *Cracoidea*
        - ♦ Family *Megapodiidae*
        - ♦ Family *Cracidae* (curassows, guans)
      - – Superfamily *Phasianoidea*
        - ♦ Family *Phasianidae* (e.g., chickens, turkeys, quail, grouse, pheasants)
        - ♦ Family *Odontophoridae* (New World quail)
        - ♦ Family *Numididae* (guinea fowl)

(Based on Kan et al., 2010; Rouse, 2005).

Studies comparing the sequence of clock-like genes and fossils are allowing a precise view of the evolution of birds. Modern bird types (*Neoornithes*) originated in the late Cretaceous period (Brown et al., 2008). Birds that can be classified as *Neornithes* or modern birds are thought to have originated about 97 million years ago (mya) during the Cretaceous period in West Gondwana (West Gondwanaland) (Claramunt and Cracraft, 2015). This land mass was made up of South America, West Antarctica, and portions of East Antarctica (see Textbox 4A Figure 1). The splits between the *Paleognathae* and *Neognathae* (about 91 mya), *Galloanseres* and *Neoaves* (about 85 mya), *Anseriformes* (duck and geese), and *Galliformes* (the taxon containing chickens, turkeys, pheasants, etc.) (72.5 mya), and within the *Neoaves* with *Columbiformes* birds splitting off about 69 mya, all occurred in the late Cretaceous period and all in western Gondwanaland (Claramunt and Cracraft, 2015). At the end of the Cretaceous period many species of birds became extinct, including the advanced ornithurines (non-*Neoornithes*) (Longrich et al., 2011). The *Neoaves* birds spread from western Gondwanaland in two routes: (1) to North America and then Europe, Asia, and Africa, and (2) to eastern Gondwanaland and then to Australia (Claramunt and Cracraft, 2015). There were multiple divergences within the *Neoaves* after the K–Pg boundary, including the Passerines (53 mya) (Claramunt and Cracraft, 2015).



PERMIAN 250 million years ago | TRIASSIC 200 million years ago | JURASSIC 145 million years ago | CRETACEOUS 65 million years ago

Textbox 4A Figure 1 The positions of the continents during the Cretaceous period when the continents were breaking up due to continental drift.

4.3 Integument (Skin and Feathers)

In poultry, the skin and feathers collectively form the integument, that is, the outer protection of the body. They (1) protect the body from injury, (2) help to maintain a relatively constant body temperature, (3) aid in flight, and (4) act as receptors for sensory stimuli.

Skin

The skin of chickens and turkeys is thin and consists of the epidermis and the dermis (see Figure 4.6); there are no sweat glands. In mammals, sebaceous glands in the skin produce sebum. This oily secretion covers the hair and skin. For birds, there is an oily cover to feathers (about 1–3% of feather dry weights) that consists of various waxes coming from both sebaceous glands and from the preen or uropygial gland. The waxes are esters of a fatty acid (including hydroxy fatty acids) and fatty alcohol covalently linked. They waterproof the feathers—this being particularly important in ducks and geese—and may provide social order cues like pheromones in mammals. The behavior of dust-bathing does not seem to reduce some of the lipids from the feathers. Oil produced by the preen gland is collected in the beak and distributed on the feathers to act as water repellant. This oil is of particular importance for aquatic species of birds.

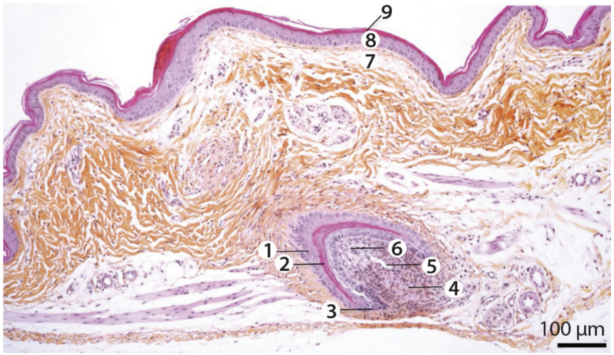


Figure 4.6 Section through the skin of a chicken. (1) feather follicle, (2) cornified cells, (3) epidermal collar, (4) dermal papilla, (5) axial blood vessel, (6) feather pulp, (7) dermis of the skin, (8) stratum germinativum of the skin, (9) stratum corneum of the skin. (Source: Courtesy of T. Larcher)

In yellow-skinned chickens, the yellow color of the skin and shanks is due to several xanthophylls (yellow plant pigments) derived from the feed. These carotenoids are deposited in the skin. Several specialized structures consist of exposed areas of skin. These include the comb, wattles (chickens), snood (in turkeys), earlobes, beak, claws, and spurs (see Figure 4.1). The comb, wattles, and snood are sensitive to the effects of sex hormones (androgens) and consequently serve as indicators of secondary sex characteristics. Male hormones cause these appendages to become enlarged.

The comb is the fleshy protuberance on top of the head. It is usually red and occurs in a number of shapes that are classified as (1) single comb, (2) rose comb, (3) pea comb, (4) cushion comb, (5) buttercup comb, (6) strawberry comb, or (7) V-shaped comb (see Figure 4.7). The wattles, which are usually red, are pendulous growths of flesh at either side of the base of the beak and upper throat. The snood in turkeys is a fleshy protuberance at the base of the upper beak. The earlobe is a fleshy patch of bare skin below each ear. It varies in color, depending on the breed. The beak, claws, and spurs are horny, keratinized structures. Additionally, the exposed parts of the legs and feet are covered with hard scales.

A. Single comb. B. Rose comb. C. Pea comb. D. Double comb. E. V-shaped comb.

Figure 4.7 Examples of comb types. (Sources: A. Taviphoto/Shutterstock; B. Yulia Plekhanova/Shutterstock; C. The Old Barn Door/Shutterstock; D. Cirasa Giovanni/Wikimedia Commons; E. Andrea Mangoni/Shutterstock)

Feathers

Feathers are epidermal outgrowths that form the external covering or plumage of birds. At hatching, birds are covered by down feathers, which are soft, fine, fluffy, plumule-like feathers. These feathers are rapidly replaced by a coarser type of feather. Feathers are made of a specific protein called beta-keratin. Adult feathers can be classified into three types:

1. **Contour feathers**. These outermost feathers can be divided into four distinct parts: (a) quill, (b) shaft or rachis, (c) fluff or under-color, and (d) web (see Figure 4.8). The quill and shaft are continuous and hollow, tapering to a fine point at the distal end of the feather. The web is formed by barbs that contain small barbules. The barbules interlock with other barbs, thereupon forming a continuous, uniform series. The fluff or undercolor is a series of barbs having no barbules. The absence of barbules causes this area of the feather to take on a scattered, downy appearance.
2. **Plumules**. These feathers form a soft downy undercoat. The rachis is short, and the barbs and barbules radiate freely.
3. **Filoplume**. These feathers have a short, flexible, hairlike rachis with barbs confined to the apex.

Feathers are distributed on the skin in well-defined tracts. Through this ordered arrangement of tracts, flight is facilitated, body heat conserved, and abrasions reduced. In periods of cold weather, muscles attached to the feathers cause them to become erect in relation to the skin, thereupon creating a thicker and more efficient insulation.

4.4 Structural Systems (Skeleton and Skeletal Muscles)

The skeletal and skeletal muscle systems are closely connected. They have multiple roles and provide structural integrity of poultry; mechanical or movement—such as flight, walking, and breathing; and meat.

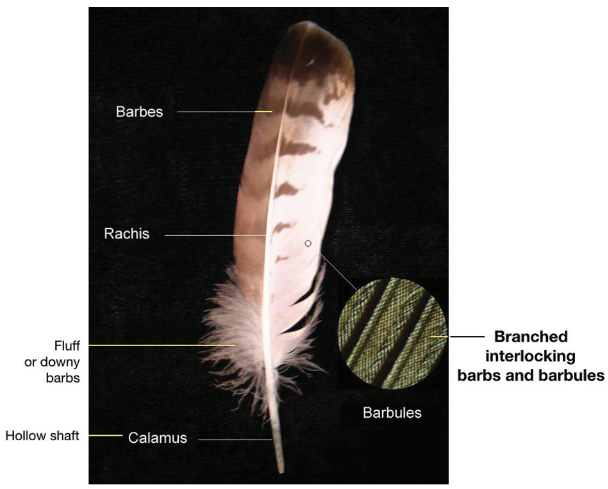
Definitions

Bipedal: Standing on two legs.

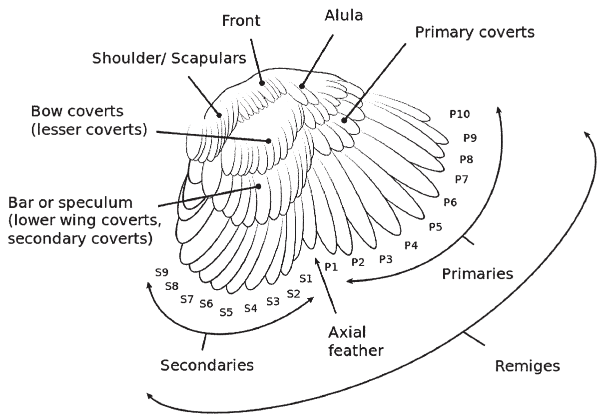
Bone: Bone consists predominantly of deposited calcium phosphate (hydroxyapatite) in an extracellular matrix of collagen together with multiple bone cells (e.g., osteoblasts, osteoclasts, and osteocytes).

Bone Resorption: Osteoclasts break down bone to enable remodelling.

Cartilage: Cartilage is essential for bone articulation. In addition, cartilage forms the bones in embryonic development. Cartilage is composed of an extracellular matrix, namely collagen and proteoglycan (glycosylated protein some of which have sulfate groups) together with cells (chondrocytes).



A. Structure of a feather. (Source: Pixeltoo/Wikimedia Commons).



B. Positioning of different feather types. (Source: KDS4444/Wikimedia Commons).

Figure 4.8 Feathers are a key identifier of birds and important to flight. They are largely a waste product in poultry production. Feathers are composed of the protein keratin.

Cortical bone: This is the dense outer bone.

Growth plate: The growth plate (or epiphyseal plate or physis) is composed of cartilage and, as its name implies, is where the long bones are growing (see Textbox 4B Figure 2).

Medullary bone: This is bone that is easily broken down and is laid down prior to egg production (under the influence of estrogen and testosterone).

Osteoclasts: The cell type that breaks down bone.

Osteoblasts: The cell type that, along with osteocytes, build up bone.

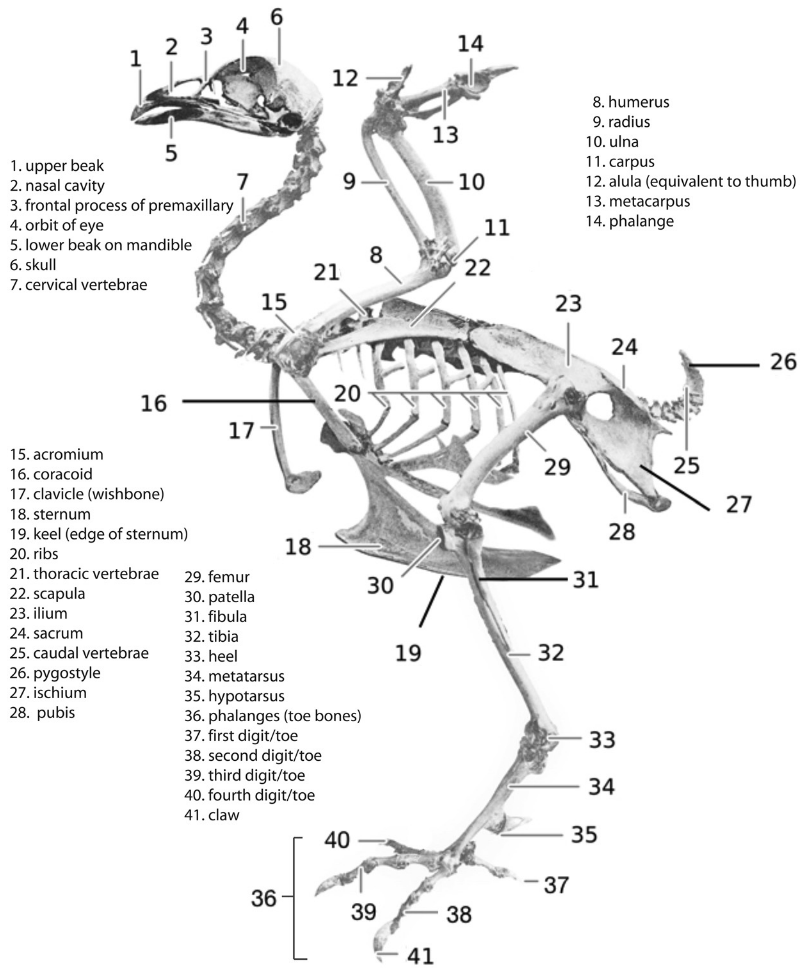
Skeletal System

Poultry are bipedal with two wings. The basic skeletal arrangement is generally analogous to that of mammals. There are obviously differences related to their ability to fly. Birds possess a pair of bones in the shoulder area, called the coracoids. This pair of bones facilitates wing movement and offers additional support for the wing. Also, several morphological differences as compared to mammals are evident in the spine. The cervical vertebrae (neck bones) form an S-shaped column

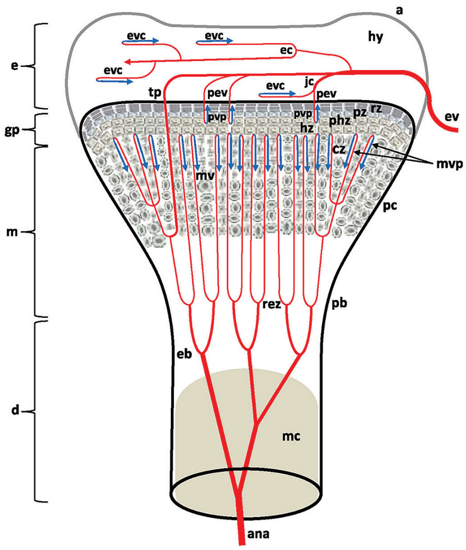
TEXTBOX 4B

A Deeper Dive: The Skeletal System of Poultry

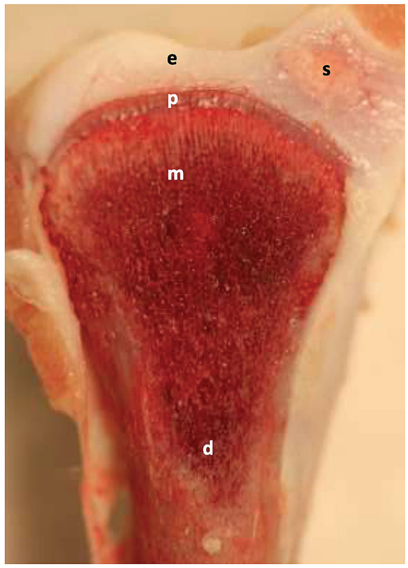
The skeletal system of the chicken is shown in Textbox 4B Figure 1. It shows the structure of the head of long bones in the leg. They consist of two tissue types: (1) true bone and (2) cartilage. The heads of long bones have a rich blood supply. There can be degeneration of the heads of tibia and femur with tissue necrosis (see Textbox 4B Figure 2). This is due to both physical changes and bacteria and is referred to as bacterial chondronecrosis (Wideman, 2016).



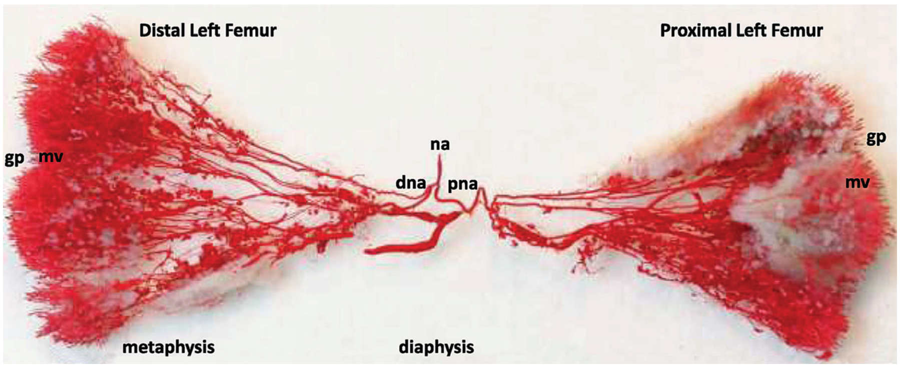
Textbox 4B Figure 1 A chicken skeleton. (Source: Adolf Bernhard Meyer/Wikimedia Commons)



A. Schematic diagram showing regions of the tibial head and the blood flow.



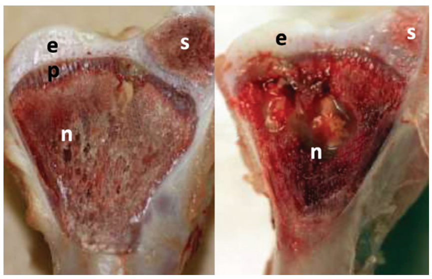
B. Bisected tibial head showing regions.



C. Vascular cast of arterial blood vessels of the femur showing high density of blood vessels in the head.

Key

ana	ascending or proximal branch of the nutrient artery
cz	calcifying zone (or hypertrophic zone) of the metaphysis
d	diaphysis
dna	distal nutrient arteries
e	epiphysis
ec	epiphyseal vascular canals
ev	epiphyseal vascular supply
evc	epiphyseal vascular capillary complexes
hy	hyaline zone
hz	hypertrophic zone
jc	junctional canals
m	medullary cavity
mv	metaphyseal vessels
mvp	metaphyseal vascular capillary plexuses
n	necrotic void
na	nutrient artery
p	growth plate or physis
pb	periosteal bone
pev	penetrating epiphyseal vessels
phz	prehypertrophic zone
pna	proximal nutrient arteries
pv	penetrating vascular capillary plexus
pz	proliferating zone
rez	resorption zone
rz	resting zone
s	secondary center of ossification
tp	transphyseal vessel



D. degeneration of the heads of tibia and femur leads to bacterial chondronecrosis with osteomyelitis in the proximal tibial head.
(left: some necrosis right: considerable necrosis)

Textbox 4B Figure 2 Proximal tibial head from a broiler chicken. (Source: Wideman, 2016. Used with permission from Oxford University Press.)

connecting the body to the head. When a flying bird lands, considerable pressure is exerted throughout the body, and this S-shaped conformation acts as a spring to minimize the impact on the head. Another difference from the mammalian spine is that the vertebrae along the trunk and body of the bird are fused together. This rigid conformation of the back provides considerable support for the wings.

The Skeleton and Breathing

The skeletal system is intimately connected to the respiratory system; many bones are pneumatic. Pneumatic bones are hollow and are connected to the respiratory system, thereby serving as a reservoir for air and reducing the weight of the bird for flight. The skull, humerus, keel, clavicle, and lumbar and sacral vertebrae are all part of this system. In fact, if one were to cut off the inflow of air through the trachea but open one of these bones, (e.g., the humerus), the bird would continue to breathe.

Skeletal Physiology in Response to Egg Production

Egg-laying places a great demand on the hen for calcium since eggshells consist primarily of calcium carbonate. To facilitate mobilization of calcium in the body for this type of production, birds have what is termed *medullary* bone. The marrow cavity of some bones is filled with interlacing spicules of bone. The spaces between the spicules are filled by red marrow and blood sinuses. In pullets, medullary bone involving the tibia, femur, pubic bone, sternum, ribs, toes, ulna, and scapula develops about 10 to 14 days prior to the laying of the first egg. At the onset of lay, the medullary bone enables the hen to mobilize calcium rapidly, so fast that if the hen is fed a diet very low in calcium she will lose 40% of the calcium in her skeleton after laying six eggs. Medullary bone is essentially absent in males or nonlaying females. However, administration of estrogen, the female hormone, together with testosterone, initiates formation of medullary bone.

Muscular System

Birds, like mammals, possess three distinct types of muscles:

1. **Smooth muscle**. Smooth muscle is the type of muscle that lines many of the organs over which the bird has no voluntary control (e.g., gastrointestinal tract and blood vessels).
2. **Cardiac muscle**. Cardiac muscle is the type of muscle found in the heart. Contraction of cardiac muscle is regulated within the heart with no outside (extrinsic) stimulus needed for the initiation of contraction. However, autonomic nerves (sympathetic and parasympathetic nerves) regulate both the rate and force of contraction.
3. **Skeletal** or **striated** (striped) or **voluntary muscle**. This constitutes most of the muscle mass in the body. It is responsible for executing voluntary movements together with other activities such as breathing.

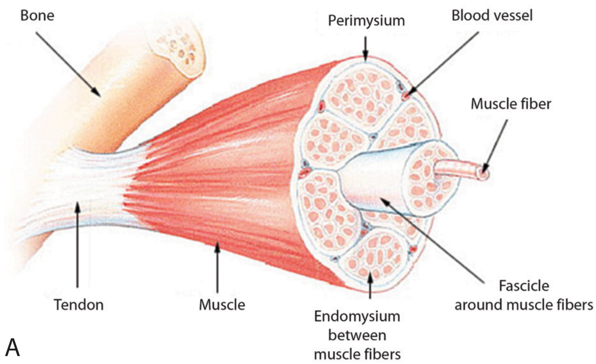
Skeletal Muscle

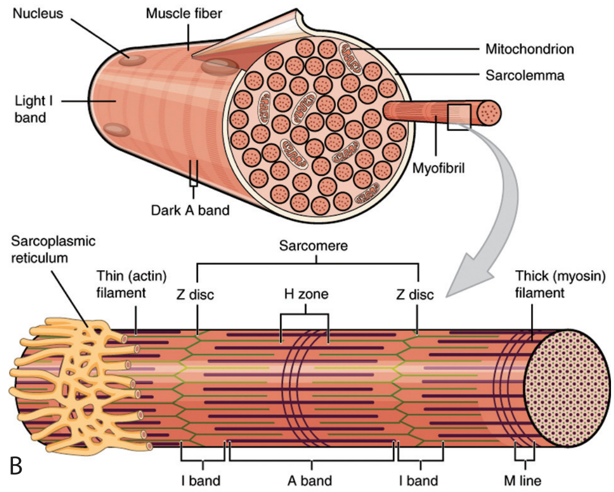
Skeletal muscle is composed of muscle fibers. These extend for the entire length of the muscle and are surrounded by sarcolemma (including the plasma membrane) (see Figure 4.9). Within the sarcolemma are myofibrils, sarcoplasm with mitochondria supplying energy (ATP) for muscle contraction and multiple nuclei. Note that muscle fibers are multinucleated. Skeletal muscle is attached to bones by tendons. The major proteins in the myofibrils are actin and myosin. In addition to muscle fibers, skeletal muscle contains nerve endings, which are essential for initiating muscle contraction, and satellite cells, which can develop into muscle fibers. Skeletal muscle grows by muscle fibers getting larger and the development of new muscle fibers.

The skeletal muscles of poultry contain five types of muscle fibers divided into two major categories based on the myofibril type (1) Fast-twitch fiber—I, IIA, and IIB; and (2) slow-twitch or tonic fibers—IIIA and IIIB. Muscles with tonic fibers predominate in white muscle. Fast-twitch fibers predominate in red muscle, which also has more blood supply and hence more hemoglobin and also more myoglobin (a protein that stores oxygen) (see Chapter 19 for discussion of chicken meat).

Red fibers predominate in what is commonly called *dark* meat. These fibers contain large quantities of myoglobin, an iron-containing, oxygen-carrying compound very similar to hemoglobin. The white fibers, collectively forming white or pale meat, contain relatively little myoglobin.

Red fibers abound in muscles that are used continuously. They receive more blood and contain more fat and myoglobin than white fibers, thereby favoring the aerobic (with oxygen) production of energy that is conducive to prolonged activity. White fibers, however, are rich in glycogen, a sugar-rich compound that is readily broken down in anaerobic (without oxygen) conditions needed to sustain brief spurts of activity. Thus, one would expect the muscles used in flight by a good flying bird to contain more red fibers than those of a poor flier. This is, in fact, the case when the pi-





A. Gross structure. (Source: US National Institutes of Health/Wikimedia Commons)
B. Structure of muscle fibers and myofibrils. (Souce: OpenStax/Wikimedia Commons)

Figure 4.9 Structure of muscle.

geon (a flying bird) is compared to the chicken (a poor flier). The pectoralis muscle (a breast muscle) of the pigeon contains about 40 times as much myoglobin as in the same muscle of the chicken.

4.5 Circulatory System

The circulatory system of birds functions much like that of mammals with a heart, arteries (blood vessels from the heart), and veins (blood vessels to the heart). The avian heart consists of four chambers: right atrium, right ventricle, left atrium, and left ventricle. The atria contract first and then left and right ventricles contract simultaneously. The left ventricle is markedly larger than the right (see Table 4.2) as the pressure achieved by contraction is much higher.

There is a double circulation in birds (see Figure 4.10) analogous to the situation in mammals. Incoming deoxygenated blood is received in the right atrium

Table 4.2 Heart and lung weights in 6-week-old meat-type chickens.

	Right	Left	Total
Lung Weight per kg Body Weight	2.9	2.8	5.8
Ventricles Weight per kg Body Weight	0.9	2.9	3.7

Data from Wideman et al., 2013.

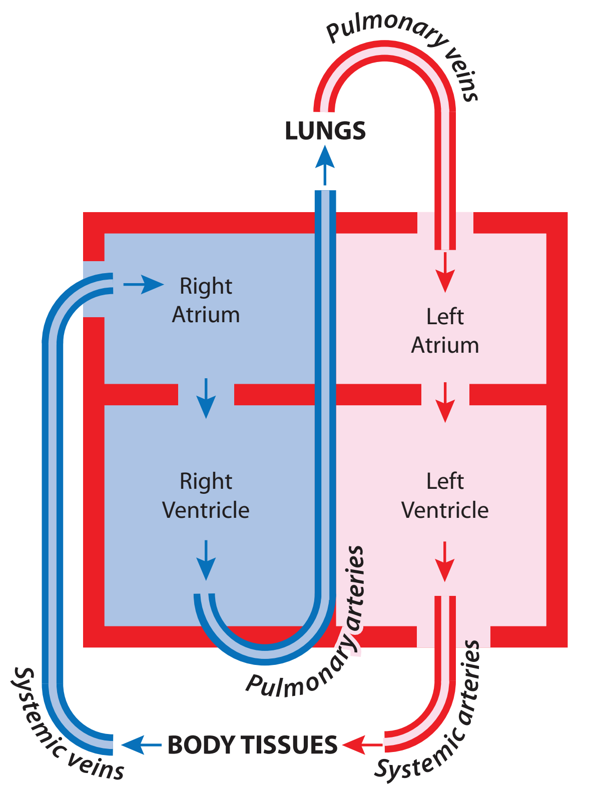


Figure 4.10 The double circulation of poultry. In the pulmonary circulation, blood is pumped by the right ventricle of the heart through the pulmonary artery to the lungs and returning to the heart via the pulmonary veins. In the systemic circulation, blood is pumped by the right ventricle to the organs of the body and returns to the heart.

from systemic veins taking blood from the organs. It subsequently passes to the right ventricle. Contraction of the left atrium forces the blood from the right ventricle to the lungs where oxygen is picked up by the blood and carbon dioxide is removed (see Figure 4.11 and 4.12). Freshly oxygenated blood travels from the lungs to the left atrium. Flow of blood is from the right ventricle to the lungs, and then to the left atrium in the pulmonary circulation, and then to the left ventricle. Upon contraction of the left ventricle, blood is pushed through the arterial system where it eventually reaches the target cells, gives off its oxygen, and picks up waste products that will ultimately be excreted. The deoxygenated blood then returns to the heart through the venous system, and the process is repeated.

Also, when the demand for oxygen and nutrients is great, such as in flying, the heart rate increases dramatically from the rate sustained when the bird is at rest, on the order of a 5- to 14-fold increase. There is considerable variation in heart rates between species, with higher rates in smaller birds (see Table 4.3). In fact, heart rate is inversely proportional to the log of the body weight of the bird.

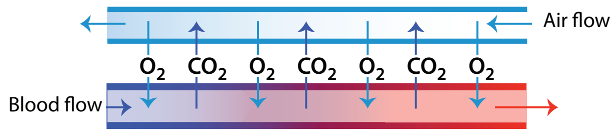


Figure 4.12 Schematic of the gaseous exchange. Oxygen (O_2) passes down a concentration gradient from the branches of the parabronchus to the blood in the pulmonary capillary. Carbon dioxide (CO_2) passes down a concentration gradient from the blood in the pulmonary capillary to branches of the parabronchus.

Table 4.3 Heart rate in birds.

Species	Heart Rate (Beats per Minute)
Chicken	350–475
Turkey	200–275
Goose	200
Pigeon	220
Ostrich	~45

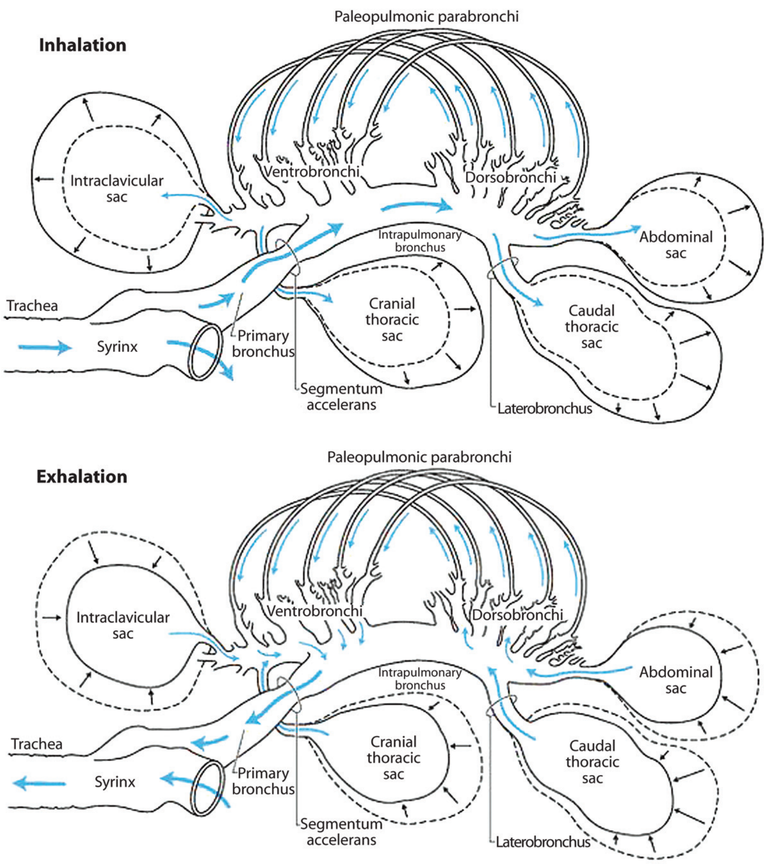


Figure 4.11 Respiratory system of the chicken during inspiration (breathing in) and expiration (breathing out). (Source: John Ludders, Michael Simmons, and Cornell University)

Definitions

Heart rate: The number of heartbeats per minute.

Stroke volume: The volume of blood pumped each heartbeat from either the right or left ventricle.

Cardiac output: The volume of blood pumped by the heart per minute.

Cardiac output (CO) = Heart rate (HR) × Stroke volume (SV)

Equivalents

- Right ventricle cardiac output = Left ventricle cardiac output
- Right ventricle heart rate = Left ventricle heart rate
- Right ventricle stroke volume = Left ventricle stroke volume
- Pulmonary blood pressure << Systemic blood pressure

Textbox 4C

A Deeper Dive: The Cardiovascular System in Poultry

Additional Definitions and Equivalents

Textbox 4C Table 1 Cardiovascular parameters in 6-week-old meat-type chickens.

Parameter	Mean
Heart rate (beats per minute)	328
Stroke volume (ml)	1.33
Cardiac output (ml/min)	434
Systemic Blood System	
Mean (systemic) arterial pressure (MAP) (mm Hg)	109
Total peripheral resistance	0.26
Pulmonary Blood System	
Pulmonary arterial pressure (mm Hg)	22
Total pulmonary resistance	0.05

Data from Wideman, 1999.

Systemic circulation (see Figure 4.10)

$$\text{Cardiac Output (CO)} = \frac{\text{Mean (Systemic) Arterial Pressure}}{\text{Total Peripheral Resistance}}$$

Pulmonary circulation

$$\text{Cardiac Output (CO)} = \frac{\text{Mean (Pulmonary) Arterial Pressure}}{\text{Total Pulmonary Resistance}}$$

In pulmonary arterial hypertension-susceptible broilers, there are elevated pulmonary arterial pressures and pulmonary vascular resistances (Wideman et al., 2013).

Poultry Blood

When blood, from poultry or other species, containing an agent to inhibit coagulation (such as heparin or ethylenediaminetetraacetic acid [EDTA]) is centrifuged, three layers are seen (see Figure 4.13). At the bottom are the formed elements—the lower and largest area is red comprising the erythrocytes covered by a thin whitish/yellowish layer. Above this is a liquid layer, the plasma. The height of the erythrocyte divided into the total height is the packed cell volume.

Packed Cell Volume

Packed cell volume (PCV or hematocrit) is determined when blood (with anticoagulant such as heparin have been added) is centrifuged. The packed cell volume is the height of the red blood cells. Table 4.4 shows examples of the PCV of chickens.

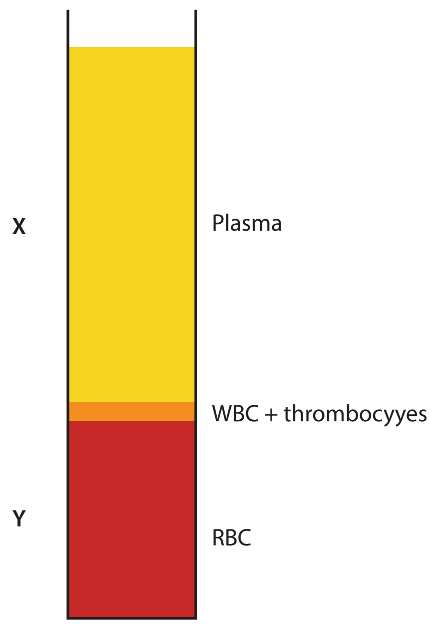


Figure 4.13 The packed cell volume (PCV), or hematocrit, is determined when blood (containing anticoagulant) is centrifuged. The red blood cells (RBC; erythrocytes) are found at the bottom, a thin layer of white blood cells (WBC; leukocytes) + thrombocytes are in the middle, and plasma is at the top. The PCV is X/X+Y but is frequently expressed as a percentage.

Table 4.4 Packed cell volumes (PCV) in chickens of different ages and genders. The lower level in adult females reflects the increase in yolk precursors.

Type	Packed Cell Volume
Adult male	43%
Adult female	29%
Young broiler chickens	< 25%

Table 4.5 Concentrations of blood cells in chickens.

Cell Type	Concentration
Red blood cells (erythrocytes) × 10^6 per µl	~3
White blood cells (leukocytes) × 10^3 per µl	25 (range 20–30)
Thrombocytes × 10^3 per µl	34

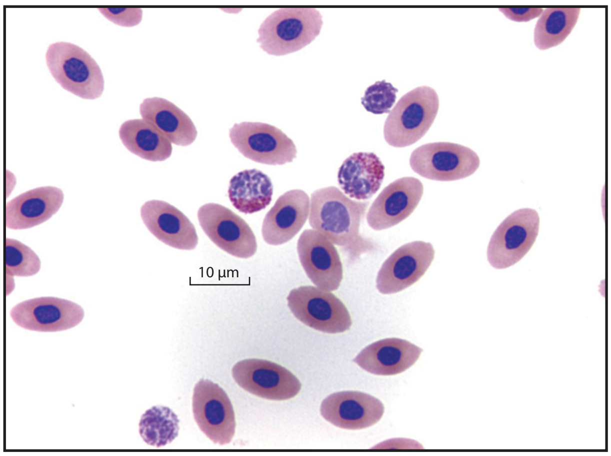
Poultry blood consists of plasma and cells:

1. **Plasma** is a light-yellowish liquid containing the following:
   - Minerals (these are essential to many critical functions including the osmotic balance of the body and nerve functioning). Minerals are present as ions:
     — Cations: sodium (Na^+), potassium (K^+), magnesium (Mg^{++}), and calcium (Ca^{++}).
     — Anions: chloride (Cl^-), bicarbonate (HCO_3^-), and phosphate (PO_4).
   - Nutrients (e.g., glucose, amino acids, and fatty acids together with trace minerals and vitamins).
   - Proteins.
     — Albumen.
     — Globulins including antibodies and transport proteins.
     — Hormones, albeit, at very low concentrations.
   - Products of metabolism: carbon dioxide (CO_2) transported as dissolved CO_2 together with bicarbonate (HCO_3^-).
   - Nitrogenous excretory products—mainly uric acid but some urea.

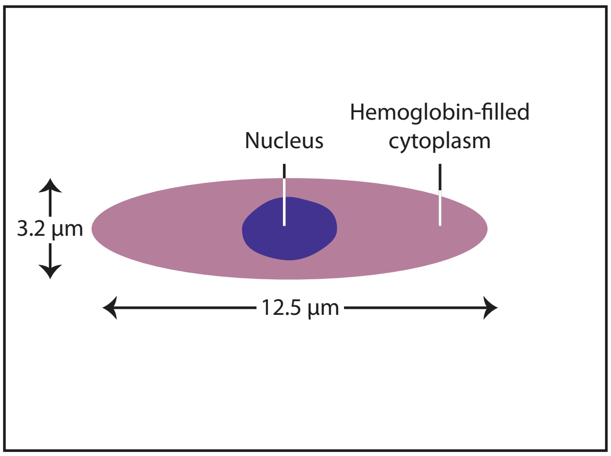
   Despite the list above, the major component of blood plasma is water.
2. **Blood cells**. Table 4.5 shows the concentrations of cells in chicken blood.

Blood cells include the following:

1. **Red blood cells** or **erythrocytes**. These are essential to the transportation of oxygen (O_2) from the lungs to the tissues bound to hemoglobin and are also important to the transport of CO_2. Unlike erythrocytes in mammals, avian erythrocytes have nuclei (for the structure of chicken erythrocytes see Figure 4.14).



A. Note that these cells have nuclei stained by hemotoxylin. In comparison, mammalian erythrocytes lack a nucleus. (Source: Kindly provided by Paul Cotter)



B. Erythrocytes have a diameter of the long axis of 12.5 µm.

Figure 4.14 Chicken red blood cells (erythrocytes).

2. **White blood cells** or **leukocytes**. These play critical roles in the defense mechanisms against pathogens (for more details see Chapter 13). Table 4.6 summarizes the relative proportion of different leukocytes in chickens: lymphocytes, heterophils (equivalent of neutrophils in mammals), basophils, eosinophils, and monocytes.

Table 4.6 Differential leucocyte counts.

Cell Type	Percentage
Heterophils	26 (range 10–35)
Lymphocytes	58 (45–80)
Basophils	2.4 (1–3.5)
Eosinophils	1.7 (1–2.5)
Monocytes	5.6 (3.5–6.5)

3. **Thrombocytes**. These are important for blood clotting and equivalent to platelets in mammals.

In contrast to the situation in mammals, both avian erythrocytes and thrombocytes each have a nucleus. Blood from poultry has a much higher viscosity than that from mammals. Oxygen is transported bound (noncovalently) to hemoglobin in erythrocytes. Most of the carbon dioxide is transported in the blood as bicarbonate with the red blood cells playing a critical role due to the presence of the enzyme carbonic anhydrase.

Tissues

$$\downarrow$$

$$CO_2 \rightarrow CO_2 + H_2O \xrightarrow{CA} H_2CO_3 \rightarrow HCO_3^- + H^+$$

Carbonic Anhydrase

Lungs

$$\uparrow$$

$$CO_2 \leftarrow CO_2 + H_2O \xleftarrow{CA} H_2CO_3 \leftarrow HCO_3^- + H^+$$

Carbonic Anhydrase

Despite having a nucleus, the lifespan of chicken erythrocytes averages from 28 to 35 days compared to about 120 days for humans. Blood volume remains fairly constant from day to day. A 5.5 lb (2.5 kg) chicken will generally have about 240 ml of blood (roughly the equivalent of 0.5 pt). Erythrocytes constitute 30% to 40% of the volume of blood, with males generally having a higher percentage of erythrocytes than females.

In the 1-week-old chick, blood represents about 8.7% of the body weight. This percentage steadily decreases as the bird becomes older, declining to about 4.6% of body weight at sexual maturity.

4.6 Respiratory System

Because of the extremely heavy demands for energy in flight, birds have developed a respiratory system that permits the greatest exchange of oxygen per unit time of any animal; yet the lungs of birds are smaller than those of mammals in relation to body size. The anatomy and physiology of the avian respiratory system differ markedly from mammalian systems. The first difference is the role of the lungs. In mammals, the diaphragm muscle controls the expansion and contraction of the lungs. Birds have no diaphragm, and the lungs do not expand and contract upon inspiration and expiration, respectively. Rather, they act solely as organs in which gas exchange in the blood takes place.

Birds possess an extensive air sac system that receives air during inspiration. Chickens have nine air sacs: the paired cervical sacs, median clavicular sac, and paired cranial thoracic, caudal thoracic, and abdominal sacs (see Figure 4.11).

When a bird inhales, inspiratory muscles increase the volume of the body cavity creating pressure lower than atmospheric pressure in the air sacs. This draws fresh air through the lungs and into the air sacs with air flowing from the higher pressure in the atmosphere to the lower pressure in the air sacs (Figure 14.15). During exhalation, the expiratory muscles decrease the volume of the body cavity forcing air out of the air sacs, back through the lungs, and out of the body. Again, air flows from the high to low pressure, this time from the higher pressure in the air sacs to the lower pressure in the atmosphere.

What Is Air Pressure and Volume?

- In a closed system, if volume goes up, pressure goes down (Boyle's law).
- If volume is decreased, pressure goes up.
- Air flows from high pressure to low pressure.

The size/volume of the air sacs is changed by contractions of the body musculature. When there is increased volume of the air sacs (and reduced pressure) air is brought in through the lungs. When there is decreased volume of the air sacs (and increased pressure) air moves out through the lungs (see Figure 4.15).

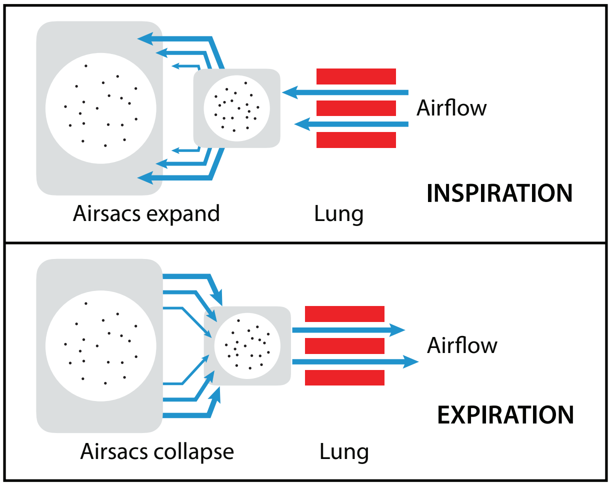


Figure 4.15 External respiration. During inspiration, the air sacs become enlarged (and hence are at a lower pressure) and air is brought through the lungs. During expiration, the air sacs become reduced in volume (and hence are at a higher pressure) and air is expelled through the lungs.

4.7 Digestive System

The digestive system of poultry differs considerably from that of nonruminant mammals. Figure 4.16 shows the gastrointestinal system of poultry. Table 4.7 summarizes the actions of regions of the gastrointestinal tract, while Table 4.8 summarizes the actions of the accessory organs of the gastrointestinal tract.

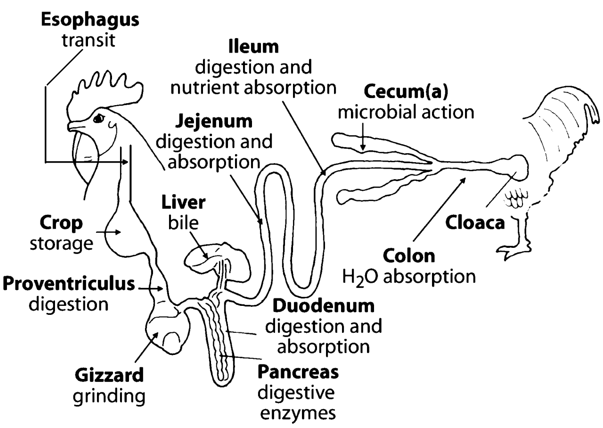


Figure 4.16 Chicken gastrointestinal tract showing regions and functions. (Source: Erik Beyersdorf/ Wikimedia Commons)

Definitions

Digestion: The process by which the constituents of feed are converted to forms that can be absorbed. This is accomplished by mechanic grinding and enzymes that chemically break down the constituent. For instance, starch in feed (e.g., in corn) is digested to glucose which is then absorbed. Proteins (e.g., in soybeans and corn) are digested to amino acids which are then absorbed.

Enzymes: Proteins that **catalyze** (speed up tremendously) chemical reactions such as:

$$\text{Protein} \xrightarrow{\textit{Proteases}} \text{Amino acids}$$

Ingesta: Materials (feed and water) that have been swallowed and are passing through the gastrointestinal tract. Alternative names for ingesta include **digesta** and **chyme**.

Absorption: The process by which digested nutrients are moved from the **lumen** (or inside) of the GI tract through the wall of the GI tract into the bloodstream.

Existing birds have no teeth; hence, there is no chewing. The esophagus empties directly into the crop, where the feed is stored and soaked. From the crop, the feed passes to the proventriculus (or glandular "stomach"), the thick-walled organ immediately in front of the gizzard. Here it is stored temporarily while digestive juices are copiously secreted and mixed with it. From there, it passes to the gizzard, a very muscular organ, where with the aid of stones or grit swallowed by the bird, the feed is crushed and ground. Then the feed moves through the small intestine, the ceca, and colon to the cloaca.

Digestion in the fowl is rapid; it requires only about 3 hours in the broiler chick and laying hen for feed to pass from the mouth to the cloaca (this is called the gut transit time). During the night, the rate of passage slows with feed stored in the crop.

Process of Digestion

Digestion can be defined as the process whereby proteins, fats, and complex carbohydrates are broken down into units small enough to be absorbed. This process is accomplished primarily through the action of digestive enzymes.

Enzymes are protein catalysts produced by cells within the body. They increase the rate of biochemical reactions at ordinary body temperatures without being used up in the process. Enzymatic activity is responsible for most of the chemical changes occurring in

Table 4.7 Functions of different regions of the gastrointestinal tract of the chicken.

Region	Function	Digestion (Enzymes)	Absorption
Mouth	Saliva added for lubrication of the feed.	Some amylase beginning digestion of starch to disaccharides.	No.
Crop	Temporary storage of ingesta.	Some fermentation of starches to lactate.	Not known.
Proventriculus	Beginning of chemical digestion. Acidification of ingesta (reducing pathogens).	Pepsin (protease) begins the breakdown of proteins to amino acids.	Little if any.
Gizzard	Grinding and ongoing effects of digestive enzymes from the proventriculus.	Continuation of chemical digestion initiated in proventriculus. Also ingesta from duodenum retrograde flow to gizzard.	Little if any.
Small intestine—duodenum, jejunum, and ileum	Chemical digestion catalyzed by enzymes from the small intestine and in pancreatic secretions. Absorption.	Amylase catalyzing starch break down to glucose. Proteases (trypsin and chymotrypsin) + peptidases catalyzing break down of proteins to amino acids. Lipase breaking down triglyceride (fat) to fatty acids and glycerol.	Glucose, amino acids, fatty acids, minerals (macro and trace) as cations, anions, and vitamins.
Ceca (2)	Microbial fermentation of ingest constituents.	Breakdown of cellulose and polysaccharides.	Significance uncertain but likely to include volatile fatty acids, B vitamins, and vitamin K.
Colon	Microbial activity and water absorption.	Probably little but continuation of microbial fermentation	Water together with ions such as sodium.

Table 4.8 Functions of accessory organs of the gastrointestinal tract.

Region	Functions
Liver	Production of bile containing bile pigments and bile salts (added to the ingest in small intestine). Storage of glucose as glycogen, a polysaccharide. Synthesis of fatty acids. Synthesis of blood proteins including some hormones. Detoxifying any harmful chemicals ingested/deactivating steroid hormones.
Pancreas	Production of pancreatic secretion (juice). This includes digestive enzymes and bicarbonate to neutralize acid. Pancreatic secretions are added to the ingesta in the small intestine.

feeds as they move through the digestive tract. A summary of the enzymes involved in the digestive process of poultry is presented in Table 4.7.

Many of the digestive enzymes are stored in an inactive form. When they are in the inactive form they are called zymogens or proenzymes. Once secreted into a favorable environment for digestion, generally governed by pH or other enzymes, these inactive enzymes "turn on" and perform their specific digestive functions.

Physiology of Digestion

The discussion of the physiology of digestion centers on the specific organs.

Mouth (Oral Region)

Two physical processes occur in the oral region of birds: **prehension** and initiation of **deglutition**. Prehension can be defined as the act of bringing food into the mouth. Deglutition is the act of swallowing. The manner in which birds pick up food and swallow it depends largely on whether they have a soft palate. Birds lacking a soft palate (e.g., chicken, goose, duck, and turkey) pick up feed with their beaks, mix the feed with saliva, and then raise their heads and extend their necks, thereupon allowing the feed to progress downward by gravity and negative pressure in the esophagus. Birds having a soft palate (e.g., pigeons) utilize this structure to help move the feed to the back of the mouth and force it down the esophagus. Thus, these birds can drink with their heads in a downward position. The tongue of birds is a rigid, heavily cornified structure in contrast to the labile, soft tongue found in mammals. Taste buds are located at the base of the tongue but are few in number.

The development of the salivary glands in poultry depends on the eating habits of the particular species being studied. Birds that consume aquatic feed have poorly developed salivary glands. Conversely, birds that eat dry feed have, by necessity, well-developed salivary glands. In some species, such as the sparrow, saliva contains amylase, an enzyme that breaks down starch. However, most domesticated birds do not secrete amylase. There are many uses of saliva in digestion, including the following:

1. **Lubricant**. These secretions act as aids in mastication, the formation of the bolus, and swallowing. Without this moisture, swallowing would be extremely difficult.
2. **Enzymatic activity**. The enzyme alpha-amylase (ptyalin) is found in the saliva of some birds, but not in chickens and turkeys. It serves to break $\alpha - 1, 4$ glucosidic linkages in starch and glycogen.
3. **Buffering capacity**. A large quantity of bicarbonate is secreted in saliva, thus serving as a buffer in the ingesta.
4. **Taste**. Saliva solubilizes a number of the chemicals in the feed. Once in solution the chemicals can be detected by the taste buds.
5. **Protection**. The membranes within the mouth must be kept moist in order to remain viable. Saliva provides one means by which this is accomplished.

Oropharynx and Esophagus

The oropharynx is the structure through which both air and feed pass. Unlike mammals, birds have no sharp demarcation where the mouth ends and the pharynx begins. However, when the neck is extended in the process of eating, there is a change in the position of the trachea that prevents the downward passage of food.

The esophagus is a muscular tube extending from the pharynx to the cardia of the stomach. The musculature and innervation of the esophagus are such that peristaltic waves move the bolus. Peristalsis is the coordinated contraction and relaxation of smooth muscles, creating a unidirectional movement that pushes the bolus through the digestive tract.

Crop

At the junction of the cervical segment and the thoracic segment of the esophagus in birds, there is a differentiated out-pouching of the esophagus called the crop. If the bird has been starved, feed will bypass this structure and go directly to the proventriculus and gizzard. As feeding progresses, the crop begins to fill and acts as a storage organ. In the crop, there is limited digestion due to microbiological fermentation. Limited absorption of glucose and volatile fatty acids in the crop has been demonstrated in some birds. The size and shape of the crop is dependent upon the eating habits of the bird. Birds consuming large amounts of grain tend to have large bilobed crops while birds that primarily consume insects have rudimentary crops or, in some cases, no crop at all. Some birds, notably the pigeon and the dove, have the ability to produce a secretion in the crop called crop milk. Crop epithelial cells become filled with lipid under the influence of the hormone prolactin and are sloughed off. This cell-rich fluid is regurgitated and fed to their young.

Proventriculus and Gizzard

Gastric digestion in birds is carried out in two separate and distinct organs: (1) the proventriculus and (2) the gizzard. The proventriculus is a small organ through which ingested feed passes rapidly. Its main function is that of gastric fluid secretion. The fluids secreted by the proventriculus are very similar to those in the stomach of the nonruminant, containing both pepsinogen and hydrochloric acid. Very little churning and mixing of feed occurs in this organ. The function of the gizzard is the mechanical action of mixing and grinding the feed. Since the bird has no teeth and swallows its feed whole, this muscular organ mixes in the ingesta during grinding. Grit, such as small pieces of granite, may be added to poultry rations to increase the digestibility of whole grains or grains with a minimal amount of processing. Grit stimulates motility in the gizzard as well as provides additional surface for grinding. When feed is provided in mash form, the benefits of grit are minimal. Modern commercial diets do not contain grit because they are finely ground.

Pancreas

The pancreas, an accessory organ of digestion, is a glandular structure that plays an essential role in the digestive physiology of poultry. The pancreas, being both an endocrine and exocrine gland, serves two physiologically distinct functions. The endocrine function is that of the secretion of the hormones insulin, glucagon, somatostatin, and pancreatic polypeptide. The exocrine function deals with the production and secretion of fluids that are necessary for digestion within the small intestine.

The pancreatic duct leads from the pancreas to the small intestine. Many of the pancreatic enzymes are stored and secreted in an inactive form that becomes activated at the site of digestion. Trypsinogen is a proteolytic enzyme that is activated in the small intestine by enterokinase, an enzyme secreted from the intestinal mucosa. When activated, trypsinogen becomes trypsin. Trypsin, in turn, can then activate chymotrypsinogen to chymotrypsin.

Liver

Some enzymes—nucleases, lipases, and pancreatic amylase—are secreted in their active form. Many of the enzymes require a specific environment before they will function. For example, amylase requires a pH of about 6.9 and the presence of inorganic ions before it will digest complex carbohydrates (see Table 4.7). In addition to the pancreas and salivary glands, the liver is an indispensable accessory organ of the gastrointestinal tract. Closely associated with the liver are the gallbladder and bile duct.

From the gizzard and small intestine, most of the absorbed nutrients travel through the portal vein to the liver, the largest gland in the body. The liver not only plays an important part in nutrient metabolism and storage, but also forms bile, a fluid essential for lipid absorption in the small intestine. The numerous physiological functions of the liver follow:

1. Secretion of bile.
2. Detoxification of harmful compounds.
3. Metabolism of proteins, carbohydrates, and lipids:
   - Regulation of blood glucose.
   - Synthesis of glucose from amino acids and other gluconeogenic precursors.
   - Fatty acid synthesis from glucose, amino acids, and volatile fatty acids (VFAs).
   - Synthesis of cholesterol.
4. Storage of vitamins.
5. Storage of glucose (carbohydrate) as the polysaccharide, glycogen.
6. Destruction of red blood cells.
7. Formation of plasma proteins:
   - Albumen.
   - Prothrombin and other clotting factors.
   - Carrier proteins for hormones, vitamins, and so on.
8. Hormonal roles include:
   - Production of hormones such as insulin-like growth factor-I (IGF-I) and hormone precursors (e.g., angiotensinogen).
   - Activation of thyroxine (T_4) converting it to triiodothyronine (T_3).
   - Inactivation of hormones.

The primary role of the liver in digestion and absorption is the production of bile. Bile facilitates the solubilization and absorption of dietary fats and also aids in the excretion of certain waste products such as cholesterol and by-products of hemoglobin degradation. The greenish color of bile is due to the end products of red blood cell destruction, biliverdin and bilirubin. Bile contains a number of salts resulting from the combination of sodium and potassium with bile acids. These salts combine with lipids in the small intestine to form micelles. Micelles are colloidal complexes of monoglycerides and insoluble fatty acids that have been emulsified and solubilized for absorption. When the micelle has been formed, the lipid can be digested and the resulting products (fatty acids and glycerol) can cross the mucosal barrier of the small intestine and enter the lymphatic system. Bile salts, however, do not travel with the lipid; rather, they are recycled into the enterohepatic circulation.

The volume of bile production is highly variable. A bird that has been starved produces little bile. Conversely, a bird fed a high-fat diet will produce substantial quantities in order to keep up with absorptive requirements. Generally, the volume of bile is dependent on (1) blood flow, (2) nutritive state of the bird, (3) type of ration being fed, and (4) the enterohepatic bile salt circulation. In many animals, the gallbladder is the storage site for bile. Several species of birds do not have gallbladders, among them pigeons and doves.

Small Intestine

The small intestine is divided anatomically into three sections: (1) duodenum, (2) jejunum, and (3) ileum. There is no histological distinction between the three sections. The first segment, the duodenum, originates at the distal end of the gizzard. Anatomists use Meckel's diverticulum as the separation point between jejunum and ileum. The length of the small intestine varies according to the eating habits of birds. Carnivorous birds (meat eaters) have substantially shorter intestines than herbivorous birds (plant eaters). This can be explained by the fact that meat products are more readily digested and absorbed than plant products. Throughout the luminal surface of the small intestine lays an extensive network of fingerlike projections called villi (see Figure 4.17). Each villus contains a lymph vessel called a lacteal and a series of capillary vessels. On the surface of the villi are a great number of microvilli, which provide further surface area for absorption.

Three types of motility can be observed in the small intestine. The first type is called pendular motion. These waves do not advance down the intestine. Rather, they are merely a localized shortening and lengthening of the intestine that produces a mixing action. Segmentation contractions are the second type of intestinal motility. These intestinal movements are ring-like contractions at regular intervals that periodically relax, whereupon the area that had been previously relaxed contracts. This type of motility provides a means of mixing in addition to the pendular contractions. Peristalsis, a form of motility that has been previously discussed, is the third type of intestinal motility, providing a means for movement of chyme (intestinal contents) down the tract.

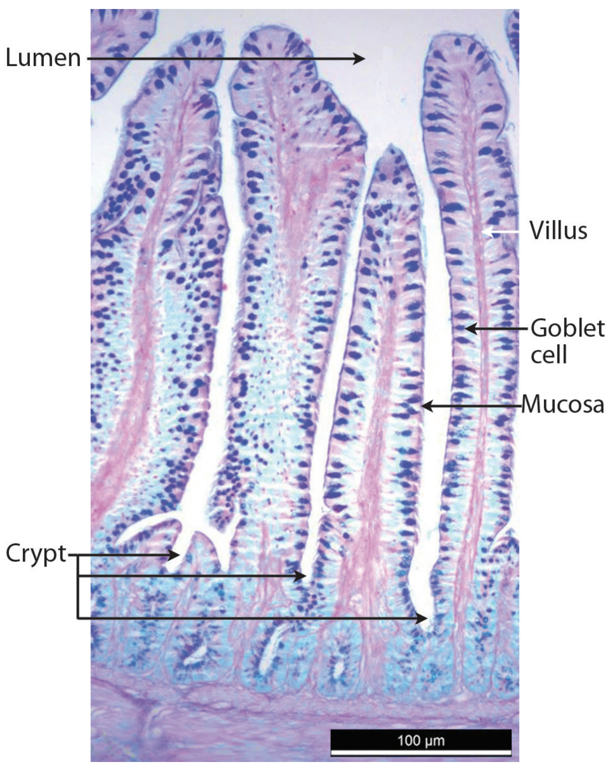


Figure 4.17 Cross-section of chicken small intestine showing villi where absorption occurs through the mucosa. The goblet cells produce mucus to protect the mucosa. (Source: Calik et al., 2017. Used with permission from Oxford University Press.)

Digestion and Absorption in the Small Intestine

The small intestine is the primary organ of digestion and absorption. Specialized enzymes present in the various segments of this long organ provide fast, effective means of breaking down carbohydrates, lipids, and proteins for subsequent absorption.

Carbohydrates. Digestion and absorption of most carbohydrates occur in the small intestine. Here, such enzymes as sucrase and maltase split carbohydrates into monosaccharides, whereupon absorption takes place. The region of the greatest absorption of sugars is in the jejunum. Glucose and galactose are absorbed through an active transport mechanism. Sodium ion concentration within the intestinal contents has been shown to be critical in this mechanism. A high Na^+ concentration facilitates rapid absorption of these sugars while a low Na^+ concentration reduces the rate of absorption. Some pentoses and hexoses are absorbed through diffusion, a process considerably slower than that of active transport.

Lipids. Lipids are digested and absorbed primarily in the upper part of the small intestine, but considerable absorption can take place as far down as the ileum. When lipids, emulsified by bile salts, come into contact with the various lipases that are found in the duodenum, they are broken down into monoglycerides and fatty acids. Short-chain fatty acids are then absorbed directly into the mucosa of the small intestine and are transported to the portal circulation. Monoglycerides and insoluble fatty acids are emulsified by bile salts, forming micelles. By attaching to the surface of epithelial cells, the micelles enable these components to be absorbed into the mucosa's cells. Once inside these cells, the long-chain fatty acids are reesterified to form triglycerides. Triglycerides then combine with cholesterol, lipoproteins, and phospholipids to form portomicrons, minute fat droplets. These are then transported by the portal blood.

Proteins. Although protein digestion is initiated in the proventriculus and gizzard, most digestion and absorption occur in the small intestine. Numerous pancreatic and intestinal enzymes split proteins into their constituent amino acids, which are subsequently absorbed. Amino acid absorption is not clearly understood, but an active transport mechanism involving Na^+, similar to that of glucose absorption, is implicated. Amino acids are rapidly absorbed in the duodenal and jejunal segments but are poorly absorbed in the ileum.

Minerals and Vitamins. Mineral absorption occurs throughout the small and large intestines, with the rate of absorption depending on a number of factors such as pH, carriers, and so forth. Numerous mechanisms of mineral absorption have been elucidated. Many minerals, for example, iron and sodium, require active transport systems. Others, such as calcium, utilize both carrier proteins and diffusion mechanisms.

Most of the vitamins are absorbed in the upper portion of the intestine, with the exception of vitamin B_{12}, which is absorbed in the lower intestine. Water-soluble vitamins are rapidly absorbed, but the absorption of fat-soluble vitamins relies heavily on the fat absorption mechanisms, which are generally slow.

Ceca, Colon, Large Intestine, and Cloaca

The large intestine consists of the colon and ceca. The two ceca (plural: ceca; singular: cecum) are blind-ended tubes found at the junction of the small and large intestines. In grain-eating birds, there are two large ceca, while in some other types of birds there may be only one rudimentary pouch, or none at all.

The colon is extremely short in birds and is very similar in structure to the small intestine. The large intestine in birds plays a much more important role in digestion and absorption than once thought. In birds, all waste products, both urinary and fecal, empty into a structure called the cloaca, which leads to the vent. Thus, urinary and fecal waste products are mixed together.

Movement of Ingesta

Ingesta are moved through the gastrointestinal (GI) tract by contractions of the muscular GI wall. These movements are controlled by nerves and hormones produced in the GI wall. The nerves exert their effects by release of neurotransmitters, such as acetyl choline, from their terminals (discussed later under "Nervous System"). In addition, there are secretions from specific regions of the GI tract and secretions from the gastrointestinal tract.

4.8 Excretory System

The kidneys in birds are rather large and elongated and are situated along the fused backbone. Each kidney consists of three lobes (cranial lobe, middle lobe, and caudal lobe). These lobes empty into a ureter leading to the urodeum of the cloaca from which urine is excreted. The primary functions of the kidney are two-fold: (1) to filter the blood so as to remove water and waste products therefrom, and (2) to reabsorb any nutrients (e.g., glucose or electrolytes) that might be recycled for additional use. Because the kidneys control the absorption and excretion of water and electrolytes, they are the primary control center for maintaining the proper osmotic balance of body fluids.

The urine of birds is cream colored. Much of it consists of a thick, pasty mucoid material that contains uric acid. Unlike mammals, whose urine contains urea primarily, birds excrete uric acid as the primary nitrogen metabolite (see Figure 4.18). Uric acid is synthesized in the liver and is excreted via the urine. It comprises 60% to 80% of the total urinary nitrogen. Birds can, however, produce urea to a limited extent as an end product of purine metabolism and the catabolism of arginine; but the level of urea found in the urine is insignificant as compared to the uric acid content. Because urine is transported to the cloaca, feces and urine are voided from the body together. In fact, some urine may pass into the colon where additional water can be reabsorbed.

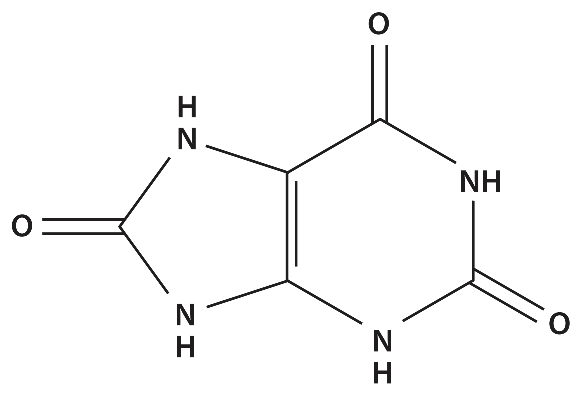


Figure 4.18 Chemical structure of uric acid. This is the major form of nitrogenous waste in birds and analogous to urea [$(NH_2)_2C = O$]. Uric acid has a lower toxicity than urea, allowing urine to be very concentrated/semi-solid.

4.9 Reproduction System

The reproductive physiology of poultry is markedly different from that of mammals. The most obvious differences are that the egg is large and yolk-filled, is fertilized in the infundibulum, is supplied with additional nutrients as egg white, is surrounded by a shell, and is expelled from the body in birds. In contrast, the very small, fertilized egg remains *in utero* receiving nutrients from the mother until birth in most mammals.

Male Reproductive System

The male reproductive system of birds is extremely simple, consisting of two very large testes, each having an epididymis and vas deferens that lead to the copulatory organ (see Figure 4.19). In male birds, the testes are located along the backbone within the abdominal cavity. In mammals, except for the elephant and marine mammals, the testes are located in a sac called the scrotum that hangs from the body. This sac keeps the testes cooler than the interior of the abdominal cavity because spermatogenesis cannot take place efficiently in mammals at normal body temperature. However, birds have evolved a mechanism that permits their intraabdominal testes to be fully functional.

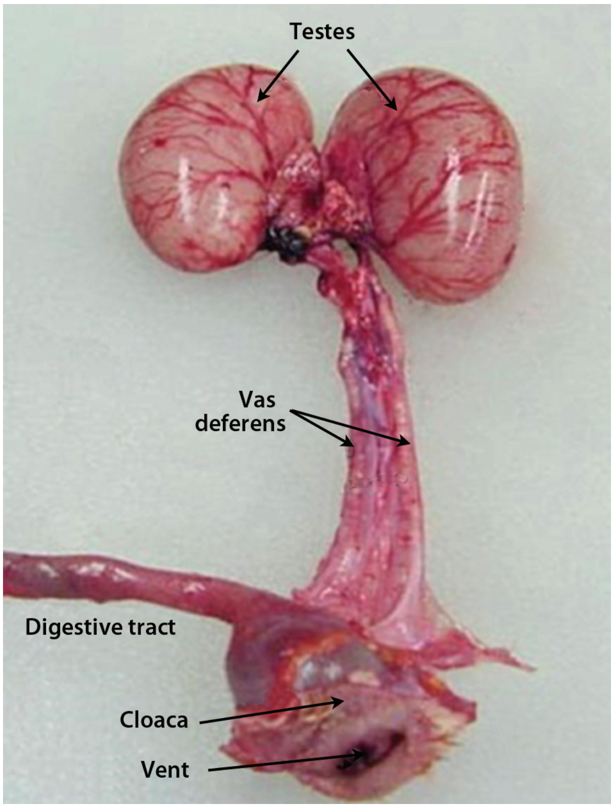


Figure 4.19 Male reproductive system together with excretory system. (Image courtesy of Jacqueline Jacob, University of Kentucky)

The process of removing the testes from young males to promote meat quality for market birds is called caponizing, and castrated birds are called capons. Because incisions must be made in the abdominal wall to remove the testes, the operation is more dangerous than the castration of mammals where the testes hang away from the body and can be easily removed. Because broilers are now marketed at about 45 days of age, well before they reach sexual maturity, caponizing is rarely performed. The copulatory apparatus for the turkey and chicken consists of two papillae and a rudimentary copulatory organ that is located at the vent. In ducks and geese, this organ is fairly well developed and is erectile in nature.

The gross appearance of avian sperm is somewhat different from mammalian sperm. It has a long cylindrical head containing the nucleus with a pointed acrosome, a short midpiece containing about 1500 mitochondria and filaments (microtubules) that extend to the tip of the tail, and a long tail (see Figure 4.20). The size of chicken and turkey spermatozoa follows.

- Chicken: Head 13.5–14 μm, mid-piece 4–6 μm, and tail (Flagella) 82 μm (Santiago-Moreno et al., 2016).
- Turkey: Head 12–14 μm, mid-piece 5–6 μm, and tail (Flagella) 66–72 μm (Korn et al., 2000).

Because the fowl has no seminal vesicles or prostate gland, the volume of seminal fluid is very low. The seminal fluid for avian sperm contains no fructose, citrate, inositol, phosphorylcholine, or glyceryl phosphorylcholine compounds commonly found in mammalian semen. Chickens normally produce about 1 ml of whitish semen per ejaculate, and turkeys produce about 0.5 ml of yellowish or brownish semen per ejaculate. Although turkeys produce only about one-half the volume of semen as chickens, the sperm concentration is about twice that of chickens. Thus, chickens yield roughly the same number of sperm per ejaculate as turkeys, about 1.75 to 3 billion.

Female Reproductive System

Females of most animals have two functional ovaries. The hen has only one *functional* ovary, the left one, which is situated in the body cavity near the backbone (see Figure 4.21). At the time of hatching, the female chick's left ovary contains up to approximately

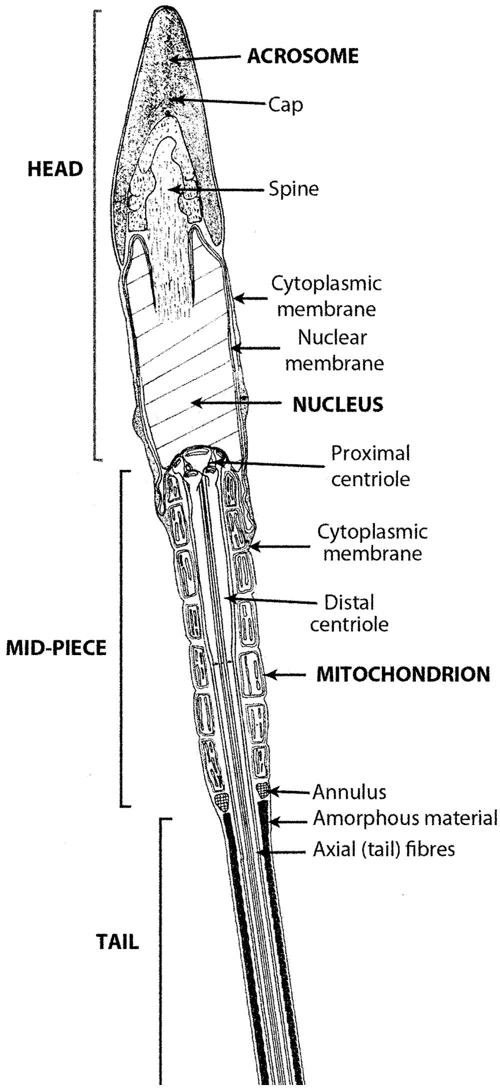


Figure 4.20 Structure of spermatozoa. (Source: Lake et al., 1968. Used with permission from John Wiley and Sons)

3,600 to 4,000 tiny ova from which full-sized yolks may develop when the hen matures.

Each follicle consists of the yolk-filled ovum enclosed in a thin-walled sac that is attached to the ovary by a stalk. This sac contains the vast network of blood vessels that supply the yolk precursors. When a pullet reaches sexual maturity, or comes into egg production, some of the ova develop to mature yolks. When mature, the yolk is released from the follicle by rupture of the follicle wall along a line called the stigma. Soon after its release, the yolk is picked up, or engulfed, by the funnel of the oviduct.

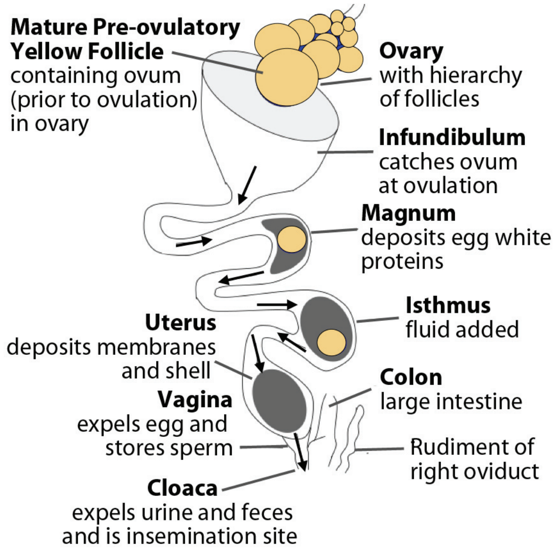


Figure 4.21 Female reproductive system: oviduct. (Source: Keyanapardilla98/Wikimedia Commons)

The oviduct is a coiled, folded tube about 25 in. (63.5 cm) long, occupying a large part of the left side of the abdominal cavity. It is divided into five rather clearly defined regions, each of which plays a specific role in the completion of the whole egg (see Figure 4.22). A normal hen requires about 24 hours to complete an egg. Within 30 minutes after the egg is laid, another ovum/yolk is released from the ovary for laying the following day. The functions of each of the five parts of the oviduct are described in Table 4.9.

The Egg

The bird egg is a marvel of nature. It is one of the most complete foods known, as evidenced by the excellent balance of proteins, fats, carbohydrates, minerals, and vitamins that it provides during that 21-day in-the-shell period when it serves as the developing chick's only source of food. It is the reproductive cell (ovum) of the hen. Upon fertilization by the sperm, the egg will develop into a chick when incubated properly. See Figure 4.23 for structure of the egg. See Chapter 18 for more information on the composition of eggs.

Fecundity

The term *fecundity* is used to describe the inherent capacity of an organism to reproduce rapidly. In higher animals, reproduction is possible only after the ovum (female gamete) is fertilized or united with the

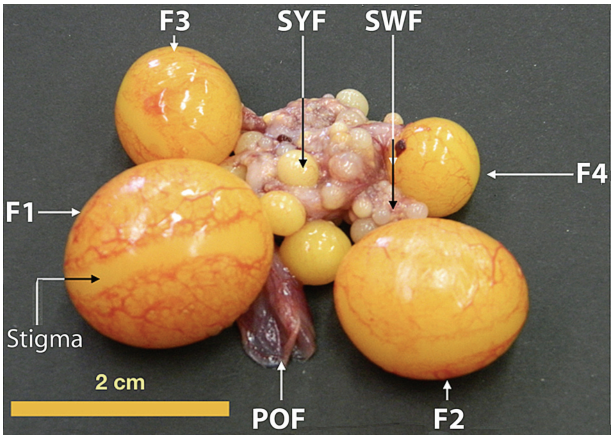


Figure 4.22 External anatomy of the chicken ovary showing hierarchy of large yellow follicles labeled F4 to F1. The post-ovulatory follicle (POF) is the remnant of the previously ovulated follicle. There are smaller follicles—the small yellow follicles (SYF) and small white follicles (SWF). The stigma lacks blood vessels and is where ovulation will occur. (Image courtesy of Jacqueline Jacob, University of Kentucky)

Table 4.9 Functions of different regions of the oviduct.

Region	Time Ovum Spends in Region (Hours)	Functions
Infundibulum	0.25	Funnel-like organ picks up (engulfs) ovulated ovum (yolk). If live spermatozoa are present, fertilization occurs here.
Magnum	3	Thick egg white proteins (albumen) deposited around the ovum.
Isthmus	1.25	Inner and outer membranes added.
Uterus	19–21	Initially fluid (plumping fluid) is added to the albumen. Shell (calcium carbonate) is added to the egg. For colored eggs, pigment is added.
Vagina	0.25	Egg rotated. Egg ejected (process called ovposition).

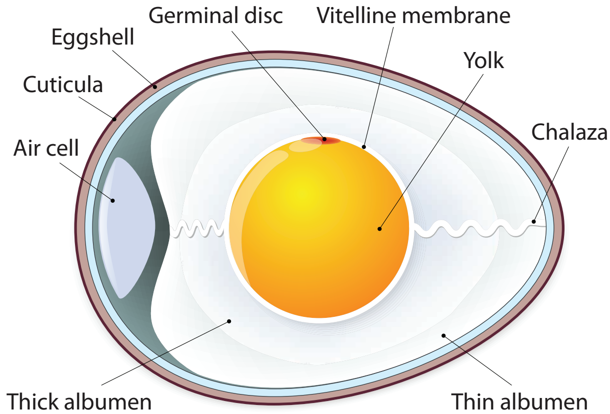


Figure 4.23 Structure of the egg. (Source: Designua/ Shutterstock)

spermatozoon (male gamete). In chickens, fertilization is not a necessary preliminary to egg-laying. Thus, the hen can lay eggs continuously without being mated or without being stimulated by the presence of a male. This biological phenomenon has been advantageously utilized in producing infertile eggs for food. Infertile eggs are of more economic value for food than fertile eggs, because there is no danger of loss through development of the embryo.

Egg Size

There is an enormous range in size among the eggs of different species of birds. Ostrich eggs average about 2 lb (~1 kg) (see Chapter 23), whereas hummingbird eggs weigh only 0.001 lb (0.5 g). There is also considerable variation in egg size in chickens; eggs of Dark Brahmas are twice as heavy as those of Japanese Bantams. It is not unusual for the price of medium-size eggs to be 5 to 10 cents lower per dozen than the price of large eggs. The most important factors affecting egg size are:

1. **Genetics**. Egg size is an inherited trait.
2. **Age of bird**. When pullets start to lay, many of their eggs will be small.
3. **Clutch order**. The order of an egg in the clutch affects its weight with the first egg of being the heaviest and there is then a progressive decrease.
4. **Feed and water**. Normally, feed is a minor factor in egg size so long as a well-balanced ration is fed.
5. **Disease**. Some diseases may affect egg size.

Textbox 4D

A Deeper Dive: Avian Reproduction

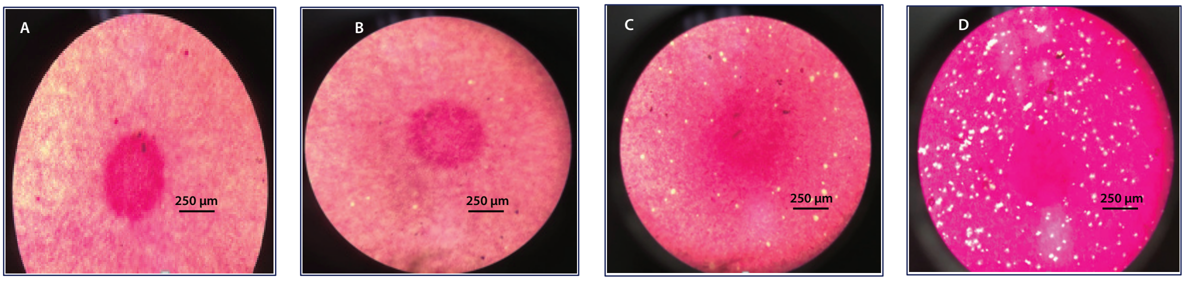
Male Fertility

- The fertility of males is very important because it determines the ratio of males to females.
- Semen for artificial insemination can be obtained by abdominal massaging.
- Semen quality is assessed by the semen quality index (SQI). This SQI consists of spermatozoa concentration, motility (%), viability (%) (viability is the percentage of sperm that are alive).

Ovulated Ovum

The ovum is surrounded by a plasma membrane. In turn, this is surrounded by the perivitelline layer or egg-envelope. This is a barrier to microbial contamination and prevents polyspermy. The extracellular matrix is homologous to the zona pellucida (ZP) in mammals which is critical to the binding of a spermatozoan (see Textbox 4D Figure 1), activation of spermatozoa, fertilization, and prevention of polyspermy.

The perivitelline layer is composed of ZP glycoproteins and can also be called the avian ZP. Most of the ZP proteins in chickens including ZP1 together with the sperm binding proteins, ZP2 and ZP3, are made by the granulosa cells surrounding the oocyte in each follicle. They are then released and deposited directly into the ZP. In contrast, ZP binding protein 1 (ZPB1) is secreted from liver cells and transported into ovary in birds.



Textbox 4D Figure 1 Spermatozoa penetration of the perivitelline layer of the fertilized ovum (increasing dramatically A through D). Binding of spermatozoa to zona pellucida proteins particularly over the germinal disc is followed by the acrosome reaction in the sperm. This is the release of proteolytic enzymes that digest a hole through the perivitelline layer to allow penetration and ultimately fertilization. The holes are seen by back illumination of tissue stained with Schiff's reagent. (Source: Courtesy of Chris McDaniel, Mississippi State University)

Egg Shape

Eggs differ considerably in shape. Although many are truly ovate, some are nearly spherical, whereas others are elongated.

Egg Shell Color

The majority of eggs sold in the United States are white but there are increases in the sales of brown eggs. The eggs of the hen may be white, many shades of brown, yellow, or even blue depending on the breed of chickens. Pigment is added in the oviduct. Commercial layers of white eggs are derived from White Leghorns and produce white eggs.

Structure of the Egg

A schematic side view of an egg is shown in Figure 4.23, with the various parts labeled in their normal position. The protective covering, known as the shell, is composed primarily of calcium carbonate, with 6,000 to 8,000 microscopic pores permitting transfer of volatile components. The air cell, located in the large end of the egg, is formed when the cooling egg contracts and pulls the inner and outer shell membranes apart. The cordlike chalazae hold the yolk in position in the center of the egg. As shown, the yolk is surrounded by membrane, known as the vitelline membrane. The germinal disc, a normal part of every egg, is located on the surface of the yolk. Embryo formation begins here only in fertilized eggs. The composition of the egg is covered in Chapter 18.

Egg Abnormalities

Periodically, a deviation in the mechanics of egg-laying will create abnormal eggs like the following:

- **Double-yolked eggs** are formed due to two follicles developing and the pair being ovulated at the same time.
- **Blood spots** are caused when a small blood vessel breaks during ovulation.
- **Meat spots** are degenerated blood clots in the egg.
- **Yolkless eggs**. Rarely, foreign material may get into the oviduct and stimulate the secretion of albumen in much the same manner as the yolk.
- **Soft-shelled eggs** result when either no shell is secreted or an abnormally small amount of shell is secreted. This may be associated with calcium deficiency.

Definitions

Egg yolk: The yolk-filled ovum. Much of yolk proteins are made in the liver and pass to the ovary via the blood stream.

Follicles: There are multiple follicles in the ovary. They are of different sizes as they fill with yolk. The largest (called the F1 follicle) is ovulated within a day. The next largest will be ovulated a day later and so on. The wall of the follicles produces hormones—progesterone, estrogens and androgens. The wall of the follicle includes theca and granules layers.

Oviposition: The process of egg-laying. It is caused by contractions of the muscular layer of hen's vagina (stimulated by the posterior pituitary hormones, mesotocin and/or arginine vasotocin together with prostaglandins).

Ovulation: The release of the ovum from the largest follicle in the ovary. This is stimulated by the anterior pituitary gland hormone, luteinizing hormone (LH).

Ovum: The female gamete. It contains the yolk within the vitelline membrane. It is equivalent to the very small ovum in mammals.

Hormones and Reproduction in the Hen

Estrogens (steroid hormone) cause the liver to make yolk precursors, stimulate oviduct to grow and produce albumin and allow the skeletal bones to store calcium. Estrogens are produced by the wall of the follicles.

Androgens (steroid hormone) with estrogens allow the skeletal bones to store calcium. In the hen, androgens are made by the wall of the follicles.

Progesterone (steroid hormone that is the pregnancy hormone in mammals) provokes increases in luteinizing hormone (LH) which in turn stimulates ovulation. In addition, progesterone with estrogen causes the oviduct to make avidin; this being a specific protein in egg white. Progesterone is synthesized by the wall of the follicle. This is unlike the situation in mammals where progesterone is synthesized in the corpus luteum and placenta as birds do not get pregnant.

Luteinizing hormone (LH) (glycoprotein) stimulates ovulation and production of steroid hormones by the walls of the follicles.

Releasing hormones, namely gonadotropin-releasing hormone 1 (GnRH1) and gonadotropin-inhibitory hormone (GnIH), stimulate and inhibit the release of LH and follicle stimulating hormone (FSH), respectively.

The reproductive system of the female chicken (see Figures 4.21 and 4.22) is characterized by the presence of a single ovary and a single oviduct. The oviduct is made up of discernible regions: infundibulum, magnum, isthmus, uterus or shell gland, and vagina.

Names of Regions of Oviduct

While the names "**uterus**, **oviduct**, and **vagina**" for the female reproductive tract of poultry are the same as parts of the mammalian reproductive tract, they are not equivalent.

Development of Oviduct in Poultry

The avian oviduct develops from one of the embryonic Müllerian ducts while the mammalian reproductive tract (oviduct, uterus, cervix, and posterior vagina) develops from both the embryonic Müllerian ducts.

The ovum (the yolk of the egg) is released from the follicle in the process of ovulation (see Figure 4.22). After ovulation, the ovum is picked up by the infundibulum. It then passes down the oviduct due to smooth muscle contractions. In the oviduct, the white/albumen, the membranes and shell are added (see Figure 4.21). If spermatozoa are present in the oviduct (following coitus/mating or artificial insemination) the ovum will be fertilized in the infundibulum. Spermatozoa are stored in sperm storage glands in the vagina and gradually released. The sperm move up the oviduct to the infundibulum after the egg has been laid. The ovum passes next to the magnum. The walls of the magnum produce egg white proteins with egg albumin being the major. These proteins together with some water are deposited around the ovum. In addition, the chalazae is formed (see Figure 4.21). This is a rope-like structure of twisted protein fibers. It is formed due to the turning of the ovum and attaching to the yolk. The ovum spends a total of about 3 hours in the magnum.

From the magnum, the ovum is passed into the isthmus where the inner and outer shell membranes are added. After spending about 1.25 hours in the isthmus, the ovum travels to the uterus or shell gland. Here water and salts (plumping fluid) are added to the egg white proteins. These pass through the membranes in a process of plumping. The wrinkled membranes become stretched out or "inflated." In this organ, the shell is formed around the membranes. The shell is composed primarily of calcium carbonate. The calcium comes from the breakdown of the bone while carbonate comes from bicarbonate which, in turn, comes from metabolic carbon dioxide. If the eggshell is to be colored, the pigments are deposited in the uterus. The egg spends about 19–21 hours in the uterus before being moved on to the vagina.

In the vagina, a thin protein coating called the cuticle or bloom is applied to the shell. When this substance dries, it seals the openings of the porous eggshell. The egg passes out of the vagina and cloaca in the process of oviposition. This is accomplished by contractions of the smooth muscles in the wall of the vagina and following stimulation by hormones such as arginine vasotocin, mesotocin, and prostaglandins of the E series. One of the interesting phenomena in the hen is that, as the egg passes down the latter uterus and vagina, it travels small end first; however, immediately prior to expulsion, the egg is turned 180° so that the large end is exposed first.

4.10 Integration of Body Processes (Nerves and Hormone)

Birds are complex biological organisms requiring considerable "information" to be passed to and from their physiological systems. This integration of messages is accomplished through multiple modes: *neural* (via nerves), *endocrine* (via blood), and localized *paracrine* and *autocrine* (local communication) mechanisms. The nervous systems provide neural transmission (action potentials or "electrical impulses") that either stimulate or inhibit specific body functions. Endocrine controls are provided via the endocrine glands and their secretions called hormones.

Definition

Hormone: A specific chemical released from endocrine cells (either diffuse or in an endocrine gland). This is transported to another region within the animal via the bloodstream where it elicits a defined physiological response.

Nervous System

The nervous system can be divided into two anatomical systems: the central nervous system (CNS) and the peripheral nervous system. The CNS consists of the brain and spinal cord. The skull and vertebral column protect these. The peripheral nervous system comprises the rest of the nervous system and is made up of nerves. Some of the nerves originate in the brain while the rest originate from the spinal cord. The peripheral nervous system is functionally divided into the somatic nervous system and the autonomic nervous system.

"Running around like a Headless Chicken"

The above saying and its variations refer to acting in a purpose-free manner. It relates to the actions of a chicken following decapitation when the chicken flaps its wings and runs. This is due to many of the skeletal muscles being under inhibitory nervous control; this inhibitory control being removed when the head is removed.

The somatic nervous system enables the body to adapt to stimuli from the external environment. Various stimuli, such as touch, are perceived by specialized receptors within this system, and the body responds accordingly. The autonomic nervous system can be further divided into the sympathetic nervous system, employing norepinephrine as the neurotransmitter, and the parasympathetic nervous system, employing acetyl choline as the neurotransmitter (see Table 4.10 for a list of major neurotransmitters and their relationship to a precursor nutrient).

The autonomic system involves the maintenance of homeostasis, the internal environment of the body. This system controls the cardiovascular system (heart rate and blood flow to specific organs) and the gastrointestinal tract. For instance, the parasympathetic nervous system increases the movement of ingesta along the gastrointestinal tract but slows the heart rate. In contrast, the sympathetic nervous system increases blood flow to skeletal muscles by reducing blood flow to the gastrointestinal tract.

Senses

For poultry to respond to the environment they employ their special senses, respectively vision (eyes), hearing (ears), and chemical senses (taste, trigeminal, and olfactory). Moreover, they have tactile and thermal receptors in their skin and other organs together with pressure receptors. In addition, there are numerous pain receptors (mechanothermal nociceptors).

Table 4.10 Neurotransmitters in the central nervous system (CNS) and gastrointestinal (GI) tract.

Neurotransmitter	Receptors	Nutrient	Present in CNS	Present in GI Tract
Acetylcholine	Cholinergic	Choline	X	X
Norepinephrine	Adrenergic	Tyrosine[1]/phenylalanine[1]	X	X
Serotonin	Serotonergic	Tryptophan[1]	X	X
Glutamate	Multiple	Glutamate[1]	X	X
Peptides				
Endorphins[2] and enkephalins[2]	Opioid	Amino acids	X	X
Other peptides[3] including NPY, gastrin, and motilin	Various	Amino acids	X	X

[1] Made from amino acids.
[2] Peptides.
[3] Some of these are also hormones produced in the gastrointestinal tract.

Definition

Receptors: There are several and distinctly different definitions of receptors. Sensory and pain receptors are modified neuron terminals. Hormone receptors are molecules that hormones bind to and initiate the cell response. Neurotransmitter receptors are molecules that neurotransmitters bind to and initiate the neural responses (e.g., nervous impulses).

Endocrine System

The endocrine system is composed of a number of glands that produce, store, and secrete hormones. Table 4.11 lists the reproductive hormones while those related to stress and metabolism are summarized in Tables 4.12 and 4.13, respectively. Other hormones are considered in Table 4.14. Hormones can be classified into two broad categories, according to structural properties: (1) protein and peptide hormones (including modified amino acids), and (2) steroid hormones. Hormones carry out their regulatory roles through several types of feedback systems as seen in Figure 4.24. Two types of feedback systems, negative feedback and positive feedback, are utilized.

Negative Feedback

Control of the various feedback systems depends on the circulating levels of various metabolites, hormones, and nutrients (Figure 4.24).

For example, if the level of calcium in the blood drops, the parathyroid gland secretes a hormone that mobilizes body calcium and subsequently increases the concentration of calcium in the blood. This increase in the blood calcium then decreases the secretion of para-

TEXTBOX 4E

A Deeper Dive: Pain Reception in Poultry

Chickens have A delta and C fiber nociceptors, or pain receptors as in mammals (Gentle et al., 2001). These nociceptors are free nerve endings of afferent fibers (going towards the CNS) and are part of the peripheral chicken sensory nervous system. The neurons can be identified using immuno-cytochemistry for substance P and/or calcitonin gene-related peptide. There are nociceptors on both the upper and lower beak that can be impacted by beak trimming (Kuenzel, 2007).

Lameness is found in broiler chickens and is presumed to be associated with chronic pain. To examine this, a model system has been developed. This involves injection of sodium urate into the leg joint of chickens (Hothersall et al., 2011). Within 3 hours, the joint becomes inflamed (with redness and swelling) and there is sensitization of the C fibre nociceptors. Analgesic drugs ("pain killers") reduce the effects in a lameness model (Caplen et al., 2013). The movements of lame chickens across an obstacle course have been compared with sound (non-lame) birds and lame birds receiving carprofen, a nonsteroidal anti-inflammatory drug:

- Sound (non-lame): 11 seconds
- Lame: 34 seconds
- Lame plus carprofen: 18 seconds

Interestingly, there is evidence that lame chickens have a higher threshold to pain than in non-lame birds (McGeown et al., 1999; Hothersall et al., 2014).

Table 4.11 Hormones controlling reproduction.

Organ	Hormone	Chemistry	Actions
Hypothalamus	Gonadotropin-releasing hormone (GnRH)	Peptide	Increases release of LH and FSH.
Anterior pituitary gland	Follicle-stimulating hormone (FSH)	Glycoprotein	Females: stimulates follicles. Males: stimulates spermatogenesis.
	Luteinizing hormone (LH)	Glycoprotein	Stimulates testes to produce testosterone and ovarian follicles to produce steroids and ovulation.
Gonad			
Testes	Testosterone	Steroid	Stimulates male characteristics such as comb, wattle, aggression, and sexual behavior.
Ovaries	Estrogens (estradiol)	Steroid	Stimulates growth of oviduct, production of albumin by oviduct and yolk precursors by liver, and storage of calcium in medullary bones.
	Progesterone	Steroid	Stimulates production of egg white proteins (e.g., avidin by oviduct).
	Androgens	Steroid	With estrogens, stimulates storage of calcium in bones.

Table 4.12 Hormones and stress in poultry.

Organ	Hormone	Chemistry	Actions
Hypothalamus	Corticotropin-releasing hormone (CRH)	Peptide	Increases release of adrenocorticotropic hormone.
Anterior pituitary gland	Adrenocorticotropic hormone (ACTH)	Peptide	Increases synthesis and release of corticosterone.
Adrenal gland	Corticosterone, the stress hormone	Steroid	Influencing carbohydrate, lipid, and protein metabolism.
	Epinephrine and norepinephrine	Modified amino acid	Effects on blood flow, heart rate and metabolism.

Table 4.13 Hormones and carbohydrate and lipid metabolism in poultry.

	Glucagon	Insulin	Corticosterone
Organ	Pancreas (α cells)	Pancreas (β cells)	Adrenocortical cells
Chemistry	Polypeptide	Protein	Steroid
Blood Glucose	↑↑	↓↓	↑
Liver Glycogen	↓↓	↑↑	↑
Fatty Acid Synthesis (Liver)	↓↓	↑↑	↑?
Triglyceride Breakdown (Adipose Tissue)	↑↑	—	—
Abdominal Fat Pad	↓?	↑?	↑↑

Table 4.14 Other hormones in poultry.

	Hormone	Action
Anterior Pituitary Gland	Growth Hormone (GH)[1]	Growth
	Prolactin[2]	Induces broodiness in turkeys and bantum chickens.
	Thyrotropin (Thyroid stimulating hormone TSH)[3]	Increase release of thyroid hormones.
Posterior Pituitary Gland	Arginine vasotocin (AVT)[4]	Water reabsorption in kidney; Stimulates uterine muscles to contract.
	Mesotocin[4]	Stimulates uterine muscles to contract.
Thyroid Glands	Thyroxine (T_4) and triiodothyronine (T_3)	Influences growth, metabolism and feathers.
Parathyroid Glands	Parathyroid hormone (PTH)	Increased blood levels of calcium.
Adrenal Cortical Cells	Aldosterone	Sodium retention.
Pineal Gland	Melatonin	Circadian rhythm.
Liver	Insulin like growth factor-1 (IGF-1)	Stimulates growth.
Kidney	Calcitriol or 1,25 dihydroxy vitamin D	Calcium absorption (intestine) and bone metabolism.
	Renin	Converts angiotensinogen to angiotensin and, thereby, increases blood pressure and aldosterone production.
Gastrointestinal tract	Multiple hormones including gastrin, ghrelin, and cholecystokinin	Controlling gut functioning and feed intake.

thyroid hormone (Figure 4.24A). Similarly, if blood concentrations of glucose fall below critical levels in poultry, the alpha (α) cells of the pancreas are stimulated to release the hormone glucagon. The glucagon, in turn, stimulates the liver to breakdown glycogen releasing glucose. The glucose enters the bloodstream restoring normal blood glucose levels (Figure 4.24B). These control mechanisms can also apply when the hormone is released in response to high blood concentrations. For instance, if blood concentrations of glucose rise above critical levels in poultry, the beta (β) cells of the pancreas are stimulated to release the hormone insulin. The insulin increases glucose storage as glycogen in the liver, thereby reducing blood concentrations of glucose. When glucose levels are returned to normal, insulin secretion stops (Figure 4.24C).

Another example of negative feedback involves a three-step process. If blood concentrations of testosterone drop, the hypothalamus is stimulated to secrete the releasing factor for luteinizing hormone (LH). This gonadotropin-releasing hormone 1 (GnRH) stimulates the anterior pituitary to secrete LH. This LH travels via the bloodstream to the testes (the Leydig cells), which are stimulated to produce testosterone. The testosterone travels to both the target cells and to the hypothalamus and pituitary where it inhibits the release of GnRH1 and LH (Figure 4.24D). In the absence of negative feedback in a capon (surgically castrated chicken), blood concentrations of LH rise to very high levels.

Positive Feedback

In a positive feedback mechanism, A stimulates B and in turn, B stimulates A, with the goal being a crescendo event like the expulsion of the fetus at the end of pregnancy. In a positive feedback hormonal mechanism, a hormone is secreted, which promotes the production of a second compound, and the second compound then travels back to the original endocrine gland and stimulates the production of even more of the initial hormone. For example, the hypothalamus is stimulated to release gonadotropin-releasing factor 1 (GnRH 1), which causes

[1] Release controlled by hypothalamic hormones. Stimulatory, growth hormone releasing hormone (GHRH), and inhibitory, somatostatin.
[2] Release controlled by hypothalamic hormone, prolactin releasing hormone (PRH).
[3] Release controlled by hypothalamic hormone, thyrotropin releasing hormone (TRH).
[4] Synthesized in the hypothalamus.

the anterior pituitary gland to secrete luteinizing hormone (LH). In addition, there is an inhibitory-releasing hormone, gonadotropin-inhibitory hormone (GnIH). LH travels to the ovary, stimulating it to produce progesterone. This in turn stimulates the hypothalamus to secrete more GnRH 1 (Figure 4.24E).

Regulation of Feed Intake

The hypothalamus is a structure in the ventral region of the brain. It plays a critical role in the control centers of feeding. Within the hypothalamus, certain areas can be differentiated. Two of these are of partic-

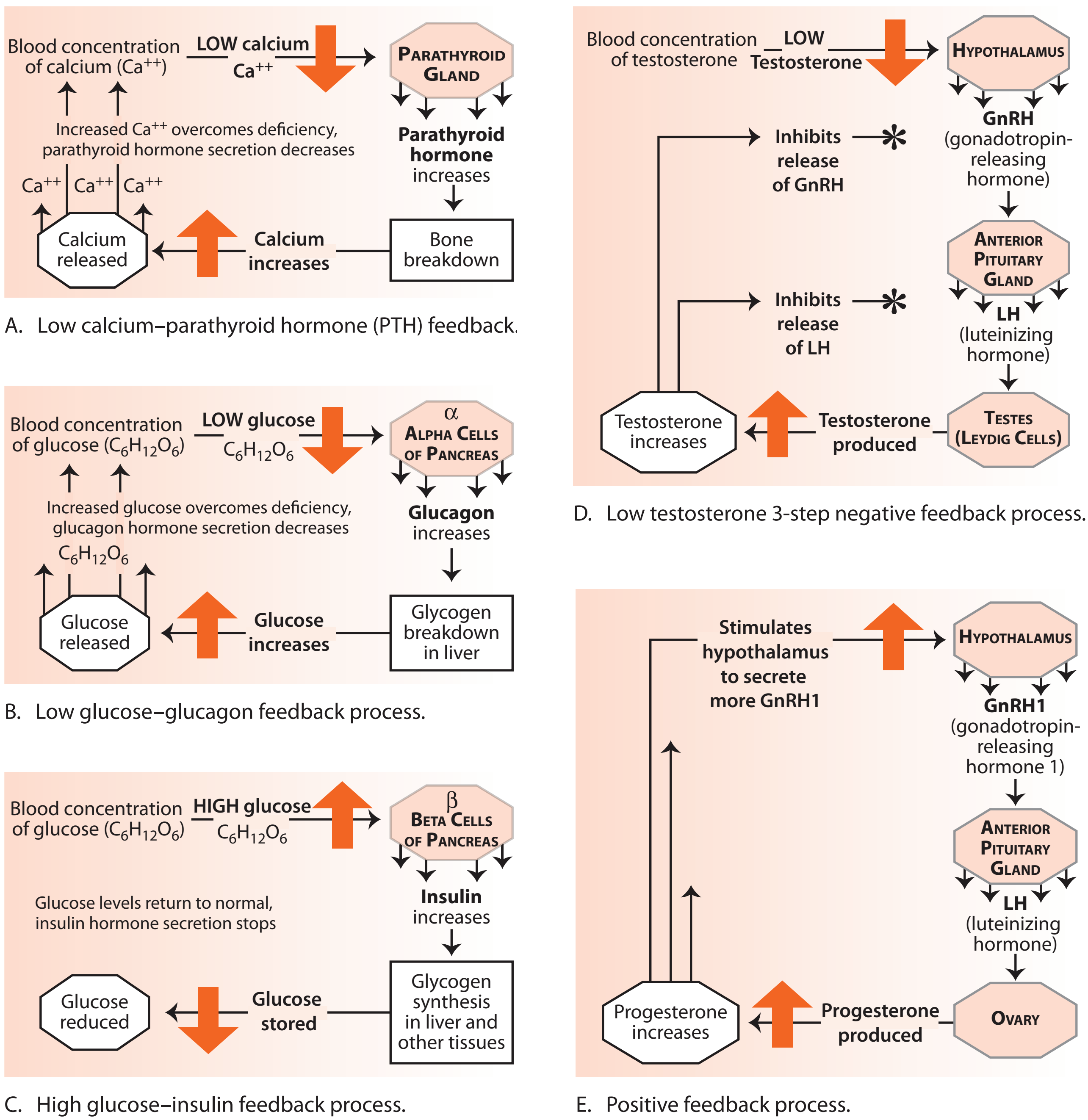


Figure 4.24 Examples of hormonal feedback mechanisms.

ular importance in the regulation of appetite. The first area is that of the lateral hypothalamus. It is commonly called the feeding center because, upon stimulation of this region, the bird commences to eat whether or not it is hungry. If this area is damaged, the bird loses all desire to eat and eventually starves. The ventromedial area of the hypothalamus functions as the satiety center. Stimulation of this region will depress appetite. If the ventromedial nuclei are destroyed, there is no inhibition of feed intake, and the bird has an uncontrollable appetite.

4.11 Thermoregulation

Birds are warm-blooded animals—homeotherms. Hence, they must maintain a constant body temperature for normal physiological functions. If the bird is in a hot environment, the body must give off heat and utilize cooling mechanisms. If the bird is in a cold environment, the body must produce heat through metabolic processes and use insulation to keep this heat from escaping. Table 4.15 shows the core body temperature of several species of poultry.

Table 4.15 Comparison on the core body temperature in poultry at rest and in thermoneutral conditions with those in mammals.

	Species	Body Temperature °F (°C)
Poultry	Chicken	106.7 (41.5)
	Turkey	106.2 (41.2)
	Duck	107.8 (42.1)
	Goose	105.8 (41.0)
	Pigeon	108.0 (42.2)
Mammals	Humans	98.6 (37.0)
	Cattle and sheep	101.5 (38.6)
	Pigs	102.0 (38.9)

Adaptation to Heat Stress

Birds have no sweat glands and must, therefore, use other means of dissipating heat. The comb and wattle areas have highly vascularized and exposed skin. Additionally, respiratory mechanisms allow for cooling, and the feathers act as a means of protecting the body from exposure to heat. The primary cooling mechanism is respiratory. When air is exhaled, heat is emitted from the areas of the respiratory tract.

Heat can be transferred from the inner body to the surface through **blood flow**, **conduction**, or **convection**. In blood flow, the circulatory system not only moves respiratory gases (O_2 and CO_2) and nutrients around the body but also moves heat. In conduction, heat is transferred from molecule to molecule in the body and is eventually lost when the heat reaches the outermost portions. Conduction is increased by the birds crouching to the ground and squashing the breast feathers to facilitate heat loss to the litter. In convection, heat is transferred from heat-producing tissues to the blood. The blood then travels to the skin, resulting in an increased skin temperature and a loss of heat to the atmosphere.

Adaptation to Cold Stress

Birds are very well adapted to cold, due primarily to their highly efficient insulation provided by feathers. When birds are exposed to cold stress, several compensatory mechanisms are used. The first line of defense is the plumage. Feathers are erected to provide more efficient protection from the environment and to conserve body heat. Birds shiver in response to cold. This activity increases the metabolic rate of the body to produce additional heat.

4.12 Effect of Light

Reproduction in poultry is extremely sensitive to photoperiod (length of daylight). Turkeys are more sensitive to the length of daylight than chickens. The wavelength of the light can affect the amount of stimulation. Orange to red (664 to 740 nm) wavelengths yield the most satisfactory results. Since incandescent light bulbs and light-emitting diodes (LEDs) emit these wavelengths, they are entirely satisfactory for light-stimulation programs.

Effect of Light on Sexual Maturity and Reproduction

When growing pullets are exposed to increasing duration of light, sexual maturity is stimulated. The increasing duration of light stimulates the hypothalamus to secrete gonadotropin-releasing hormone (GnRH) that, in turn, stimulates the anterior pituitary to release LH and FSH. Chickens require as little as about 0.5 to 1.0 foot-candle of light (5.4–10.8 lux) to stimulate egg production. Generally, a 14- to 16-hour light program is used. The length of light exposure should not be decreased for layers in production. If egg production is started at too early an age, the eggs will be too small to be profitable. Thus, most producers utilize a growing program designed to suppress sexual maturity in pullets until they reach an age and size when marketable-size eggs can be produced.

Clutches

Hens lay eggs in a certain time pattern called a clutch. For example, a hen may lay an egg on each of 10 consecutive days and on the eleventh day fail to produce an egg. This pattern is repeated. Another hen may have a pattern of eggs laid for 3 successive days followed by a missed day. Generally, each successive egg of a clutch becomes smaller. The weight of the yolks remains relatively constant, but the amount of albumen decreases as the clutch progresses. Clutches are determined by the hormonal cycles in the hen and are highly variable, ranging from 1 day to as many as 200 days. Genetic selection has extended clutch length.

A hen having a three- or four-egg clutch (Figure 4.25) has an ovulation cycle of about 26 hours. The 2-hour difference over the 24 hours in 1 day is called lag. The "missed day" allows the hen to get back into synchrony. As the clutch becomes progressively longer, there is a reduction of the length of the ovulatory cycle to a minimum of 24 hours, normally. Genetic selection has reduced the length of the ovulatory cycle. Most hens on a photoperiod of 14 hours of light and 10 hours of darkness program lay their eggs in the morning between 12 to 16 hours after the beginning of the dark period.

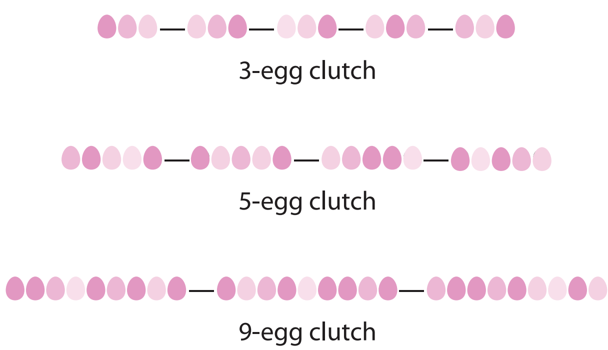


Figure 4.25 Clutch pattern of egg-laying with one egg laid each day followed by a missed day of oviposition.

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5

Poultry Behavior

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Define poultry behavior.
2. List the major senses in poultry and how they differ from ours.
3. Understand how poultry communicate?
4. Describe vocalizations of chickens and turkeys.
5. Explain the relationship between crowing and social hierarchies.
6. Define ultradian and circadian rhythms.
7. Understand what a social hierarchy is and how it is linked.
8. List the major components of the control of food intake.
9. Understand why and how often chickens undertake dust baths.
10. Describe sexual behaviors.
11. Provide examples of poultry behaviors related to thermoregulation.
12. Define cannibalism and its consequence to poultry production.

5.1 Introduction

Poultry do more than produce eggs and/or meat. This chapter will briefly cover poultry behavior, or ethology. Chickens exhibit responses to novelty and stressors (discussed in Chapter 12) with, for instance, less time devoted to preening. Substantial evidence is being developed leading to a greater understanding of the behaviors of poultry in natural or experimental conditions. Chickens exhibit fear, anxiety, exploratory behavior, and social motivation.

It is useful for poultry scientists to have some understanding of poultry behavior. Domestication has influenced poultry behavior as have the environments under which poultry are raised. Genetic selection for growth or egg-laying has influenced the behaviors of poultry. It is not clear whether behaviors expressed in natural conditions are per se beneficial to the animal.

What Is Ethology?

Ethology is the study of animal behavior. We know that birds, including poultry, exhibit complex behaviors.

Who Was Konrad Lorenz?

Konrad Lorenz (1903–1989) was an Austrian zoologist who pioneered studies on imprinting with geese. He was one of the founders of the field of ethology and received the Nobel Prize in 1973 (along with Nikolaas Tinbergen and Karl von Frisch). Lorenz found that if a newly hatched gosling was exposed immediately after hatching to some moving object, person, or animal, it would adopt that object as its parent-companion (see Figure 5.1). Young chicks show a similar relationship with the hen after hatching and incubating in traditional systems and with chickens that show brooding and broodiness (discussed below in Section 5.8).

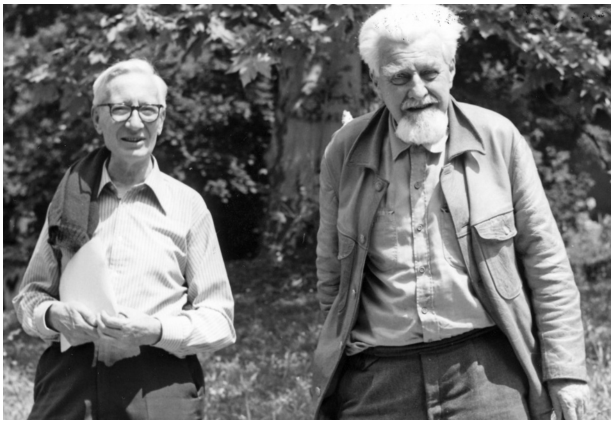


Figure 5.1 Two giants in the field of animal behavior/ethology were Nikolaas Tinbergen (left) and Konrad Lorenz (right). (Source: Max Planck Gesellschaft/Wikimedia Commons)

Behaviors to be discussed include vocalizations, other communications, feeding-related behaviors, other activities (e.g., walking, standing, laying down, sleeping, and dust bathing), sexual, maternal and chick behaviors, aggressive behaviors and fighting, and behaviors related to temperature control. Genetic selection may accentuate behavioral issues or provide an answer to correcting behavioral problems or adapting poultry to their environment. Prior to discussion of the behaviors, senses of poultry will be presented.

5.2 Senses and the Central Nervous System Functioning of Poultry

Poultry have a capacity to see, hear, detect chemicals, learn, and remember. An obvious example is chicks finding the location of feed and water and returning repeatedly. This involves processing visual inputs, potentially chemoreception, learning, and memory. In chicks, the ability to learn improves with age following hatching.

Another example of learning is habituation—getting used to, or ignoring, certain stimuli. An example of habituation is the response of turkey poults to the warning call of the mother when there is impending danger. At first, they "scamper" for cover or to the corners of their pen, pile in clumps, and remain motionless for several minutes. However, they gradually get used to a repetition of this call, with each response becoming less intense. It is argued that ducks do not have to learn to swim, they instinctively take to water.

Senses

Vision and hearing are the most highly developed senses in the bird. They play a crucial role in social behavior, communication, and responses to predators. Chemical senses are also important.

Vision

Birds have a well-developed sense of vision. The eyes are large compared to the size of the head and brain. The number of optic fibers in the chicken optic nerve is 2.5 times that in man. The position of the eyes in the orbits gives chickens and turkeys a visual field of approximately 300 degrees. Because of the rather flat eyeball, there is little eye movement. Birds can follow moving objects by moving their head and neck. Chickens and turkeys possess color vision including the ability to detect ultraviolet light. Chickens have four different color photoreceptors (compared to three color photoreceptors in humans and two photoreceptors in dogs and most mammals).

Hearing

Birds have a very well-developed sense of hearing despite having an inconspicuous external ear. Chick embryos can detect auditory stimuli. Birds are as sensitive to sound as mammals, including humans. This is not surprising given the importance of "calls" between both birds in the wild and poultry (e.g., birds in the wild establishing territories and "baby" chicks being attracted by maternal calls).

Chemical Senses

The ability of an animal to detect chemicals is divided into (1) taste (gustation), (2) olfaction, or smell, and (3) trigeminal chemoreception. Taste is the detection of chemicals in direct contact with the taste buds at fairly high levels. Birds have few taste buds. These are located on the base of the tongue and the floor of the pharynx. The total number of taste buds in the chicken is 24 compared with 9,000 in man. The taste buds can detect salt, acid (sour), and possibly sugars. Taste is involved in ensuring the well-being of both chickens and turkeys.

Olfaction is the ability to detect very low levels of chemicals in the air. The olfactory receptors are in the nasal conchae. The ability of birds to detect odors seems to be comparable with that in mammals. In some bird species, olfaction is extremely important and very sensitive; for example, vultures finding dead animals by the odors.

There is a third chemoreception system. Trigeminal chemoreceptors in the mouth detect chemically-induced pain. An example of this in humans and mammals is the response to hot peppers (in fact, to the ingredient capsaicin). Thus, capsaicin can be a repellent for mammals. Birds do not avoid capsaicin, although they can detect it and be trained to avoid it. There is a well-developed trigeminal system in birds that can be affected by some aromatic chemicals, leading birds to be averse to these chemicals.

5.3 Vocalizations

Vocal communication is of special interest because it forms the fundamental basis of human language. Sound is also an important means of communication among animals. Vocalizations in chickens are especially important in mother–young relationships and the crow is emblematic of chickens. Vocalizations in chickens include the following:

1. Embryo calls
   - Distress calls. This is followed by the hen returning to sit on the eggs.
2. Chick calls
   - Distress call or peep (declining frequency with high volume). These are referred to as "the call of the isolated chick" or "the call of the chick when alone."
   - Short peeps (declining frequency, low volume, and short duration).
   - Warbles—repetitive elements at a low volume.
   - Pleasure notes (increasing frequency and low volume).
3. Hen vocalizations
   - Pre-lay call (before the hens enter a nest to lay an egg).
   - Post-laying cackle.
   - Clucking: These calls are slow and rhythmic to bring together the chicks as a brood and allow the chicks to distinguish between different hens.
   - Roosting calls: These calls are purring-like but not rhythmic and encourage chicks to congregate under the hens' wings (e.g., before night) (see Figure 5.2).
   - Feeding calls: A broody hen makes a feeding call when she discovers food. The feeding call is high-pitched and rapid. This call together with the hen pecking is to bring the chicks to a source of food. It is also to encourage the chicks to eat.
4. Rooster vocalizations
   - Crowing (discussed below).
   - Alarm calls (high volume).

Figure 5.2 Hen brooding with chicks nestling under the wings. (Source: Nataliia Melnychuk/Shutterstock)

Textbox 5A

A Deeper Dive: Neuropeptides and Distress Vocalization

Administration of corticotropin-releasing hormone (CRH) (into the ventricle within the brain) increases distress vocalization and active wakefulness in chicks (Kurata et al., 2011). This is reduced by the amine ornithine and the amino acid aspartate (Kurata et al., 2011; Erwan et al., 2012). Corticotropin-releasing hormone (CRH) also stimulates the release of adrenocorticotropic hormone (ACTH) from the pituitary gland which in turn stimulates the production of corticosterone from the adrenal cortical cells (see Chapter 4).

A rooster's crow sounds like "cock-a-doodle-doo." The crow helps avoid direct aggressive encounters and is a means of reinforcing dominance and recognition since a given rooster crows much the same and crows differ greatly between roosters. The duration of a crow differs between breeds and is highly heritable. While roosters crow at different times during the day, it is well known that they crow consistently before dawn. This was used by earlier human societies for timekeeping.

Interesting Factoids

For Christians—Roosters Crowing Early in the Morning

In Matthew 26:34, Jesus speaks to Saint Peter:

> "Jesus said unto him, Verily I say unto thee, That this night, before the cock crow, thou shalt deny me thrice."—*King James Version*
>
> "Truly I tell you," Jesus answered, "this very night, before the rooster crows, you will disown me three times."—*New International Version*

Rooster's Crow—Cock-A-Doodle-Doo in a Nursery Rhyme

> "Cock-a-doodle-doo! My dame has lost her shoe" —Original
>
> "*Cock-a-doodle-doo! What is my dame to do?*"—This latter version appeared in a murder pamphlet over 400 years ago.

Definition

Circadian rhythm: An endogenous rhythm or a rhythm within an animal or plant. The circadian rhythm is entrained to exactly 24 hours by environment cues; being set to the light–dark cycle.

Textbox 5B

A Deeper Dive: A Rooster's Crow

There have been a few recent discoveries about roosters crowing (see Textbox 5B Figure 1):

- The pre-dawn crowing is set by a circadian rhythm in the brain of chickens (Shimmura and Yoshimura, 2013).
- The most dominant rooster crows first before dawn followed by the second most dominant, etc., in the social hierarchy (Shimmura et al., 2015).

Textbox 5B Figure 1 Rooster crowing. (Source: Dima Fadeev/Shutterstock)

Vocalization in Turkeys

Vocalizations of turkeys include (1) the trill emitted during threat behavior and as the vocal component of the male strut; (2) yelps given by hens in attracting the poults; (3) various vocalizations given by the poults—a distress peep, a trilling contentment call, a high-pitched scream-like call when pecked, and the sleepy call just before going to sleep; (4) the gobbling call of the male, which appears to serve as individual recognition within the flock (if one turkey gobbles, usually most of the males in the vicinity follow suit; at the height of the breeding season, a male turkey will respond with gobbling to a wide variety of stimuli); and (5) a frenzy of vocalization when young poults are attacked by a predator.

5.4 Other Forms of Communication

In addition to auditory communication, there is visual communication between animals. This type of communication involves one individual giving some sign or signal that, on being received by another, influences its behavior. In poultry, these stimuli are auditory (discussed above) and/or visual. Among the important visual displays of poultry are (1) raised hackles (feathers on the top of the neck) to denote aggressive intentions and make birds look larger and more formidable; (2) a low crouch in a submissive response; and (3) the waltz plus wing-flutter in a displacement reaction. Birds are especially noted for their sexual behavior in the act of courtship.

5.5 Feeding-Related Behaviors

Genetically increasing feed intake is one of the primary causes for rapid improvement in the growth of broiler chickens (Figure 5.3).

Food intake is regulated in poultry, as it is other animals, by specific areas in the hypothalamus within the brain. The amount of feed consumed is controlled by (1) appetite (increasing feed intake) and (2) satiety or fullness (decreasing feed intake). There are multiple factors that influence feed intake:

- Time of day with eating occurring during the day but not the night. There is a peak of feeding before lights out.
- Crop and gizzard fill or distention (reducing feed intake) (e.g., influenced by the hormones ghrelin and cholecystokinin).
- Hormones from the intestine and adipose tissue (leptin) (reducing feed intake).
- Nutrients (e.g., sugars) acting on the brain or elsewhere (reducing feed intake).
- A complex series of peptides and other neurotransmitters in the hypothalamus.

Free-range chickens may spend about half their time foraging and feeding (with ~14,000 pecks at food per day). A chicken's foraging behaviors include scratching and ground pecking. Each species has its own particular method of ingesting feed. Chickens and turkeys ingest their feed by pecking, while ducks scoop their feed with their broad, soft bills. Chicks do not peck much until their second day after hatching, presumably due to digestion of yolk since the yolk sac is resorbed during and following hatching. Normal pecking experience requires some light. Initially, chicks peck and ingest both nutritive and nonnutritive substances. Chickens feed almost exclusively during the day (hours of light) with increased feeding (anticipatory feeding) prior to the beginning of the night.

The number of birds feeding at any given time is influenced by (1) dominance relations, (2) appetite, and (3) feeder space. After having been fed, a dominant bird may return when subordinates begin feeding, thereby increasing its consumption and potentially reducing the feed consumption of those in the lowest rank.

5.6 Other Activities

Table 5.1 shows an example of the time budget of turkeys in either confinement or free-range conditions. The top five activities are (1) pecking at the litter, (2) laying down, (3) preening, (4) feeding, and (5) walking.

Figurer 5.3 Chickens eating (A) and drinking (B). (Photos courtesy of Jiaying Wu, Purdue University, and Dr. Heng-wei Cheng, USDA Agricultural Research Service)

Table 5.1 Time budgets (% of time spent during the morning) of turkeys either held in confinement or free range.

Activity	Free Range	Confinement
Aggression	5.7	5.7
Drinking	5.3	8.9
Feather pecking	5.4	6.9
Feeding	8.4	14.2
Immobility	2.1	5.6
Jumping	2.3	2.2
Litter pecking	17.2	21.3
Lying	17.1	11.6
Preening	14.1	11.9
Standing	9.2	4.4
Walking	13.1	7.4

Calculated from Irfan et al., 2016.

Low light intensity reduces walking, foraging, exploration, and feather pecking (and therefore cannibalism). Turkeys spend the night laying down, standing up between two and twelve times. There is a marked tendency for growing chickens to cluster rather than distribute themselves randomly across the environment.

When perches are provided, laying hens spend about a quarter of the time during the day **perching**, and more at night (see Figure 5.4). The availability of perches, and hence the ability of chickens to perch, has consequences. There is evidence of greater bone strength. In addition, there are accidents in landing, leading to bone breakages and keel bone deviations.

Preening activity spreads oils from the preen gland, or uropygial gland, to wax or waterproof the feathers (also discussed in Chapter 4). If litter or other loose materials are available, chickens and turkeys also show **dust bathing** behavior (Figure 5.5). This removes excess lipids from the feathers. Ducks and geese groom by shaking movements to remove water from the feathers, distributing oil to the feathers from the uropygial gland above the tail, and wetting the feathers during bathing. These activities are necessary to keep the feathers in good condition, preserve waterproofing, and for thermal insulation.

Dust bathing is considered a "high priority behavior" by the European Union. When allowed, chickens perform dust bathing (rolling in the dirt) with fine particles. This occurs approximately every other day with the complete activity taking about 25 minutes. The purpose of dust bathing is thought to be to remove lipids and ectoparasites from the feathers. The high motivation of chickens to dust bathe is seen with chickens that are deprived of litter. When they can dust bathe, they do so very quickly.

Normal behavior in sleep should be recognized, especially since it differs widely between species. Chickens and turkeys may wind their claws tightly around a pole, or roost, or snuggle closely together. They can close their eyes and hide their heads in the feathers of their wings. Ducks and geese sleep on both land and water. On land they often drowse while standing on one leg; on water they paddle every now and then, in order not to drift ashore. The eyes frequently

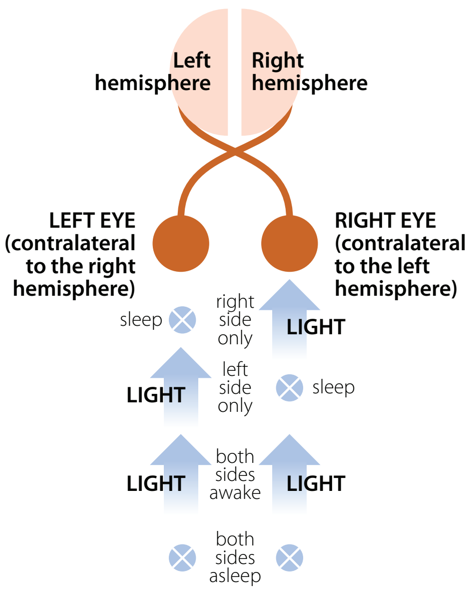
Figurer 5.4 Chickens perching. (Photo courtesy of Jiaying Wu, Purdue University, and Dr. Heng-wei Cheng, USDA Agricultural Research Service)

Figure 5.5 Chickens engaged in dust bathing. (Source: Carrie Epley/Shutterstock)

Textbox 5C

A Deeper Dive: Sleeping in Chickens

Chickens and other birds have the ability to be in slow-wave sleep or REM sleep. Chickens can be asleep in both hemispheres in the brain simultaneously (as in humans) or have only the left or right hemisphere asleep in what is called **unihemispheric sleep**. When one hemisphere of the brain is asleep (slow-wave sleep), the contralateral eye will be closed (see Textbox 5C Figure 1) while the ipsolateral eye may be open (monocular-unihemispheric sleep). When both hemispheres are asleep (bihemispheric sleep) both eyes are shut (binocular-bihemispheric sleep) and there can be either slow-wave or REM (rapid eye movement) sleep. It is possible to deprive chickens of sleep by enforced locomotion. When the chickens are allowed to sleep, there are up-ticks in both binocular and monocular sleep. When one hemisphere is asleep, the other may be asleep or awake with fast-waves. (Sources: Bobbo et al., 2009; Mascetti et al., 1999; Mascetti and Vallortigara, 2001; Nelini et al., 2010; Rattenborg et al., 2000).



Textbox 5C Figure 1 Schematic of the relationship between left and right eyes with hemispheres of the brain in the chicken. Chickens have the ability for only the left, only the right, or both hemispheres to be asleep.

blink open, and sleeping birds can become fully alert instantly if disturbed. Turkeys are inactive, laying down and sleeping, during the period of darkness. Chickens have the ability to keep all of the brain asleep (like us) or either the right or left side (while the other side is awake). A chicken can be literally half asleep!

5.7 Sexual Behaviors

It is important that poultry scientists have a working knowledge of sexual behavior as well as other aspects of reproduction (discussed in Chapter 4). Sexual behavior involves courtship and mating together with behaviors associated with egg-laying. These are under hormonal control. Each species has a specific sexual behavior to prevent interspecies mating.

Courtship Behavior in Chickens

In chickens, the male typically takes the initiative in sexual behavior. There are a variety of approaches by which a cock/rooster may evoke a sexual response in the hen. The most spectacular of these is the wing-flutter, waltz, or dance. These initial sexual reactions of the rooster is called courting. A hen may be indifferent to courting, or she may respond either negatively or positively. As a negative reaction, she may step aside, walk or run away, or struggle if captured. These types of avoidance of the male by the female may be accompanied by vocalizations varying in intensity from faint screams to loud squawks. A positive reaction to courting takes the form of a crouch, often with head low and wings spread. This behavior has been called a sex invitation, or crouching. The sexual crouch is a strong stimulus for the rooster to mount and tread, particularly when the rooster approaches from the rear. The male stands on the outstretched wings, grasps the comb or hackle of the hen, and moves the feet up and down in a treading manner. Subsequently, the male rears up, the hen moves the tail to one side, and each everts the cloaca as vents meet. The male usually steps off in a forward direction and the hen shakes herself vigorously as she gets to her feet. She may run in an arc and the cock may execute a waltz (see Figure 5.6).

Mating Behavior in Chickens

Chickens are polygamous. Sexual behavior is referred to as mating behavior. Mating in chickens is preceded by various behavior patterns known as displays or courting, which synchronize sexual activities

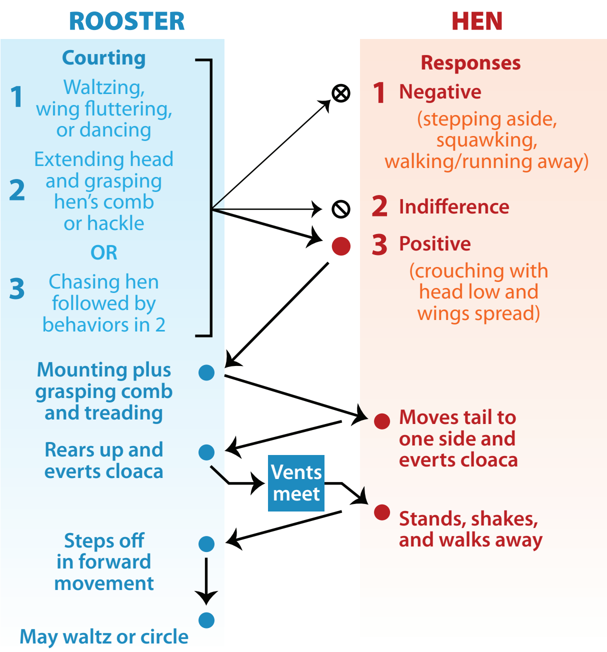


Figure 5.6 The series of interactions between the rooster and hen during mating.

Figure 5.7 Chickens engaged in mating. (Source: n ole/Wikimedia Commons)

of males and females (see Figures 5.6 and 5.7). Preferential or nonrandom mating has been observed in both roosters and hens. Additional information on the sexual behavior of chickens follows:

1. Both early social experience and hormonal level influence the level of sexual behavior.
2. The earlier the separation of males from females, the less the sexual performance of males.
3. The relation of sex hormones and sexual behavior is established.
4. When several roosters are placed with a flock of hens, the dominant one (the one ranking highest in the peck order) is usually most successful in mating, fertilizing a large number of eggs, and siring the most chicks.
5. Dominance among hens can interfere with mating.
6. There are differences in mating frequency of males belonging to different sire families.

Behaviors Associated with Oviposition/Egg Laying

Prior to egg-laying, hens may show a variety of behaviors including (1) nest building (rudimentary); (2) restlessness, including pacing; and (3) vocalization (pre-laying calls)

Mating Behavior in Turkeys

The mating behavior in turkeys tends to follow a chain reaction similar to chickens. That is, the behavior of one sex partner elicits a specific response from the other, and, in turn, that response elicits a further response from the first partner. However, differences exist between the sexual behavior of chickens and turkeys. The movements of chickens during courtship and mating are more rapid and the feather display of the male is less elaborate than in turkeys (see Figure 5.6). Male chickens may force matings, but this behavior is not seen in turkeys. Turkey females sometimes follow the male and crouch near him, whereas female chickens seldom approach the male before crouching. Although males of both species move away if another male attempts to mount, roosters may tread each other, whereas male turkeys will not. In commercial turkeys, artificial insemination is used because a full-sized tom turkey will damage the hen during coitus.

5.8 Maternal and Neonatal Behaviors

Parental and Filial Behavior (Maternal and Filial Behavior)

Parental behavior is confined to females in poultry. Hen behaviors can be summarized as (1) laying eggs in a nest, (2) incubating eggs, and (3) maternal behavior(s) to chicks (broody behavior). There are close filial attachments between chicks (or duckling or goslings) and the mother hen. The precocial chicks imprint on the hen. They learn her appearance and vocalizations. There is vocal communication between the chicks and the hen. The hen produces different vocalizations including alarm calls.

Textbox 5D

A Deeper Dive: Broodiness

Some people want to see poultry able to express their natural behaviors. This can contrast with the goals of commercial production such as the number of eggs produced. Broodiness is an example of a behavior that is disadvantageous, with egg production suppressed for three weeks. Broodiness is made up of two behaviors:

1. Incubation-related behaviors with the hen sitting on the eggs (spending much more time in and more frequently visiting the nest), retrieving eggs, and appearing to protect the eggs. During this time, egg production stops.
2. Maternal or brooding behaviors caring for the chicks.

The overall system controlling broodiness in birds involves the pituitary hormone, prolactin, stimulating incubation behavior. Prolactin acts via prolactin receptors in the brain—the more a bird sits on the nest, the more prolactin is released so that there is more nest sitting. The release of prolactin is controlled by the releasing hormone vasoactive intestinal peptide (VIP) (see Textbox 5D Figure 1).

Chickens

Broodiness was effectively bred out of commercial laying chickens over 60 years ago (Hutt, 1949). This occurred as chickens were bred for egg production, or specifically for persistence of egg-laying. It was tempting to think that the loss of broodiness was due to differences in the prolactin receptor. This is situated on one of the sex chromosomes, namely the Z chromosome (ZZ male or ZW female chickens) (Dunn et al., 1998). There have been studies of crosses between White Leghorn (modern layers non-broody) and Bantam chickens. From these it was concluded that broodiness is under genetic control by more than one partially dominant autosomal genes (Romanov et al., 2002).

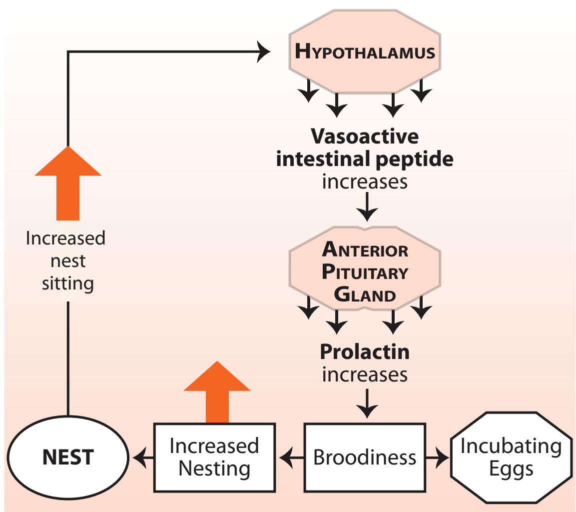
While broodiness is not seen in commercial chickens, it is still present in some breeds such as Bantam types (discussed in Chapter 6) together with indigenous chickens. Broodiness is one of the reasons for the low productivity of village chickens (see Chapter 3). Moving to artificial incubation in a village system is projected to result in marked improvements to the well-being (nutrition) of the people.

Turkeys

Broodiness is found in domestic turkeys. It is controlled by the prolactin system (Textbox 5D Figure 1) with the hypothalamic release of VIP under serotonergic and dopaminergic neural systems (e.g., El Halawani et al., 1995a; Bakken et al., 2014). There have been successful experimental strategies to overcome broodiness, including immunizing the birds against prolactin or VIP (Crisóstomo et al., 1998; El Halawani et al., 1995b; 2000).

Conclusion

Broodiness is under genetic control and physiological control by prolactin. Prolactin is necessary but not sufficient for broodiness.



Textbox 5D Figure 1 Schematic of the control of broodiness in chickens and turkeys.

Definitions

Filial: Pertaining to a son or daughter.

Precocial: When chicks, poults, ducklings, and goslings hatch they are able to act independently. They are covered in fine feathers, can see, walk around, feed themselves, and drink water. This is referred to as precocial. It is similar to the situation with foals, calves, and lambs.

Altricial: The converse of precocial. Young are born or hatch in a much less mature form. They are often unable to see, naked, and unable to walk around. This is seen in wild birds, such as starlings, and mammals, such as rats and cats.

Ultradian rhythms: Activities that are repeated at regular intervals during the day and can be synchronized. The advantage of this to young chicks facilitates them staying together with their mother, the hen.

Modern incubators have replaced the setting hen and precluded the need for broody hens. As a result, breeders have increased egg production by selecting against this trait. Few hens and chicks are allowed to run together. Nevertheless, when this happens maternal behavior can be intense. For example, hens hover over their chicks by covering them with their spreading wings and nestling them close to their bodies during the night or at other periods when they rest or need protection. A hen with chicks exhibits a definite antagonistic behavior and will attack any enemy that bothers her young. To warn her chicks of danger, she emits a loud, shrill cry. The chicks react quickly and seek protection.

Domestic hens adapt to laying in artificial nests, although some individuals must be trained to use them. The termination of laying and the start of incubation are closely related. Decreased levels of broodiness are desirable under domestication. Fortunately, selection against broodiness has been very effective in chickens.

5.9 Aggressive Behaviors and Fighting

The Red junglefowl is the ancestor of domestic chickens. Both adult female and male junglefowl have home ranges. Male junglefowl are territorial, protecting their territory through aggression, display, crowing, etc.

Why Some Wild Birds Are Aggressive

It is thought that aggressiveness has distinct advantages as the aggressive birds get more food, territory, and offspring than less aggressive birds. Poultry species also exhibit aggression. The aggressive behaviors of roosters form the basis of cockfighting. This so-called sport is illegal in the United States and much of Europe and results in bad injuries or death. Aggression in male chickens is seen earlier than females. In laying hens, aggression can directly lead to wounds in the skin and this may ultimately lead to cannibalism. Male turkeys exhibit high levels of aggression towards other males. Again, this can lead to injuries and mortalities.

Aggressive Behaviors

Aggressive behaviors in chickens include (1) downward pecking towards the head or neck, (2) feather pecking (gentle or harsh) around the cloaca, and (3) threatening behavior with the neck held erect and hackle feathers raised. These behaviors are seen more frequently when the birds are under high-intensity lighting. A threat was defined as one bird standing with its head (maybe only slightly) in front of another bird.

Castration, Roosters, and Scientific Development

It has been known since at least the time of Aristotle in 350 BC that castration greatly reduces aggressiveness in livestock and poultry and facilitates handling of the animals. Arnold Berthold (1803–1861) was a German physiologist at the University of Göttingen in Lower Saxony (in present day Germany). In 1849, he developed the concept of hormones—secretions of one organ that passes through the bloodstream to influence other organs including the brain and hence behavior. The concept was based on castration studies with roosters. As expected, castration was followed by regression of the comb and wattle and cessation of mating, crowing, and aggression. When testes were transplanted, the comb and wattle re-grew and mating, crowing, and aggressive behaviors were again observed. This was related to the appearance of blood vessels to the transplanted testes. Thus it was concluded that something coming from the testes affects the other organs—at the time a revolutionary concept.

A Modern Synthesis

Testes → Testosterone → Blood → Brain—aromatized → Estrogen → Acts on estrogen receptors → Aggressive behaviors

Aggressive Behaviors in Chickens

This type of behavior includes fighting and threatening behaviors. Among all species, males are more likely to fight than females. Nevertheless, females may exhibit fighting behavior under certain conditions. Castrated males are usually quite passive, which indicates that the hormone testosterone is required for these behaviors. Fighting rarely results in death; it usu-

TEXTBOX 5E

A Deeper Dive: Aggression in Poultry

There is strong genetic influence on aggression in chickens. In one study, 33 SNP (single nucleotide polymorphisms) on chromosome 4 were associated with aggression (Li et al., 2016). The gene responsible has been narrowed further to one gene strongly related to level of aggression; namely the neural protein, sortilin-related VPS10 domain-containing receptor 2 (SORCS2) gene (Li et al., 2016). When the SORCS2 gene is "knocked down," there are marked decreases in the expression of dopamine receptors (Li et al., 2016).

Pharmacological studies provide evidence for the involvement of both serotonergic and dopaminergic nerves in the control of aggressive behaviors in the brain:

- Administration of dopamine D1 receptor agonist (mimic) resulted in increased frequency of aggressive pecks on subordinates [activate dopamine D1 receptor–aggression ↑]. The implication is that when dopamine binds to dopamine D1 receptors, there is increased aggression.
- Administration of dopamine D2 receptor antagonists (blockers) resulted in decreased frequency of aggressive pecks on subordinates [block dopamine D2 receptor - aggression ↓]. The implication is that when dopamine binds to dopamine D2 receptor, there is increased aggression.
- Administration of serotonergic receptor blockers (5-HT1-A and 5HT1-B antagonists) was followed by increased aggression [block serotonergic receptors - aggression ↑]. The implication is that when serotonin binds to serotonin receptors, there is decreased aggression (Dennis et al., 2008; Dennis and Cheng, 2011; Buitenhuis et al., 2009).

ally continues until one gives up. In chickens, agonistic behavior includes attack, escape, avoiding, and submissive behavior.

Cockfighting is illegal in most of North America and Western Europe. However, it was widespread through human history and still occurs in some countries. The ancient Greeks regarded the cock/rooster as the symbol of pugnacity. Legend has it that the sight of two fighting cocks had emboldened the Athenians to take up the struggle with the Persians. In commemoration, annual cockfights were held in Athens and other Greek cities. The Romans added iron spurs to the sharp claws of the cocks so that a fight became more lethal. There are great differences in aggression between breeds of chickens, with meat breeds being quite placid.

Aggressive Behaviors in Turkeys

Fighting often occurs when two strange turkeys meet for the first time, and the winner of the fight subsequently dominates the loser. The aggressiveness of male turkeys depends on their reproductive condition. Turkeys on short day lengths are quiescent reproductively and show low aggressiveness. Turkeys on long day lengths are reproductively active and can show tremendous aggressiveness. Aggressive encounters can lead to serious consequences such as broken wings. Groups of young turkeys raised together establish their social hierarchies at 3 to 5 months of age.

Turkeys exhibit a variety of threat displays, ranging from mild threat (head raised, looking at the opponent) to strutting (against other males). During the threat display, the birds vocalize in a distinctive trill of relatively high pitch. Actual fighting begins by both birds jumping at each other with their feet extended forward. If one bird lands a stroke on the other's back, the latter gives up. Following 1 to 20 jumps, combat shifts to a tugging battle in which the head is darted forward to grasp the caruncles, snood, wattle, or beak of the opponent. Simultaneously, they tug and push in an attempt to force the opponent's head downward. A fight is terminated by submission, with the loser retracting its snood, lowering its head, attempting to hide under the victor's breast, and fleeing. The winner may chase and peck the defeated bird.

5.10 Social Hierarchy (Pecking or Peck Orders)

In poultry, there is a social organization. The ancestral form for domestic chickens is the junglefowl. The social unit of junglefowl is thought to be a rooster with 4 to 12 adult females and immature offspring. Females and male chickens have a social hierarchy or pecking order. Similarly, turkeys have a highly competitive system leading to the establishment of a social hierarchy.

Definitions

What Is a Social Organization?

Social organization can be defined as an aggregation of individuals into a fairly well-integrated and self-consistent group in which the unity is based upon the interdependence of the separate organisms and upon their responses to one another.

What Is a Social Hierarchy?

A social hierarchy is a system where animals or people are ranked by their authority. Social hierarchies are most frequently stable.

In chickens and many other animals housed together, there is a social hierarchy. This is referred to as the "pecking order" in chickens and can be readily determined numerically by the numbers of aggressive pecks (attacks) given by dominant birds and the number received by the subordinate or victim. A stable hierarchy is established by about the time of sexual maturation.

When a number of strange hens or roosters are placed together, fights or threatening can occur, establishing a dominance-subordination order or "peck order." The "winner" of each contest has the "right" to peck the loser, and the latter usually avoids the former. At subsequent meetings, one member of each pair pecks or threatens the other, and it exhibits submissive behavior. A definite dominance-subordination pattern or peck order is thus established. Submission in hens is characterized by crouching. Fighting between hens is less serious than between roosters.

Factors influencing the peck order of chickens are aggressiveness, appearance, level of gonadal hormones, experience, and breed differences. When we restrict or confine birds and force them into spaces that bring them within the individual distance that has been established, we may create stress. Thereupon, the dominants have to pay more attention to maintaining their dominance and to protecting their own field of territory. They may be more aggressive. The subordinates become more nervous and this can spread throughout the group.

5.11 Behaviors Related to Temperature Control

The high deep-body temperature, the absence of sweat glands, and the very effective insulation provided by the plumage characterize avian thermoregulation. Panting is the main method of evaporative water and heat loss in birds (see Figure 5.8). The most conspicuous thermoregulatory behavior of birds is movement to warmer or cooler areas.

Poultry respond to thermal stress by moving away from a heat source, increasing respiration rates (to assure evaporation cooling of the air sac system and oral mucosa surfaces), decreasing feed consumption, changing body position—spreading their wings as they crouch on the ground (so that air can circulate past the less insulated undersurface of the wings, and so that squashing of the breast feathers facilitates heat loss to the soil), and opening the mouth and panting.

In a cold environment, the chicken reduces surface area, and hence its heat loss, by hunching. An additional reduction in heat loss, amounting to 12%, may be achieved by tucking the head under the wing. A still further savings of 20 to 50% can be made if the chicken sits rather than stands, thereby reducing the

Figure 5.8 Chickens panting and extending their wings in response to elevated temperatures. (Courtesy of Jiaying Wu, Purdue University, and Dr. Heng-wei Cheng, USDA Agricultural Research Service.)

heat loss from the un-feathered legs and feet. It should be noted that poultry are exposed to daily changes in temperature and humidity even in the best environmentally controlled housing.

5.12 Behavior and Poultry Production

The poultry producer needs to be familiar with behavioral norms of birds in order to detect and treat abnormal situations, especially illness. Two of the behavioral signs of good health are alertness and eating.

Undesired Behavior

Abnormal behavior can provide a way in which to recognize diseases early. Sick birds usually eat less, may be dull and inactive, and may isolate themselves from the rest of the flock. Layers produce fewer eggs, and fertility and hatchability of eggs decline. Other undesirable behaviors are feather picking, cannibalism, stereotypes, and flightiness.

Feather Picking

Poultry can pull or peck at feathers of other individuals. This vice can lead to cannibalism for dead or dying birds. It can be controlled by beak trimming, reduced light intensity, and reduced population density.

Cannibalism

Cannibalism may be encountered among birds of all ages. Among "baby" chicks, the trouble is usually confined to toe and tail picking. With mature birds, the vent, tail, and comb are the regions most frequently picked. The cause of cannibalism is not fully understood. It is more frequent under confined conditions. Without a doubt, it may be accentuated by deficiencies in management and nutrition. It may also be caused by high light intensities. The best way to control cannibalism is by beak trimming.

Stereotypies and Flightiness

Stereotypies are repetitive behaviors. Chickens confined to small cages in laying batteries will develop stereotyped head movements. Another example of an abnormal behavior is flightiness. Flightiness occurs particularly in Leghorn chickens. In response to noise or sudden movements and high light intensity, birds may "jump" on top of each other, resulting in injury and death.

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6

Poultry Genetics and Breeding

CHAPTER SECTIONS

OBJECTIVES

After reading this chapter, you should be able to:

1. Understand generally the importance of genetics and breeding to poultry.
2. State what has been magnitude of the effects of the application of genetics in the development of commercial poultry production.
3. Define the central dogma of molecular biology, DNA, RNA, a gene, histone, a chromosome (sex or autosomal), chromatin, the genome, and epigenetics.
4. Define diploid, haploid, dominant gene, recessive gene, and the genome.
5. Understand what is a genotype and phenotype.
6. Define heterosis, transgenics, and sex-linked genes.
7. Provide examples of dominant and recessive autosomal and sex-linked loci and how they influence comb-type, color of plumage, dwarfing, and egg color.
8. Give the differences in the genetic approaches employed when breeding chickens for meat or eggs or when breeding turkeys.
9. List the major poultry primary breeders.
10. Understand the goals and approaches for poultry breeders.
11. Describe genetic gain, the breeding pyramid, primary breeder, pedigree line, and quantitative trail loci.

6.1 Introduction: The Importance of Genetics to Poultry Production

Globally, there are about 5.5 million layer parents (parents of pullets) and 500 million broiler parents (broiler breeders). Greater progress in efficient production has been accomplished by the application of genetics to poultry than with other livestock. Table 6.1 shows the changes in broiler performance in the United States over the last 80 years. Key features are a reduced time to market (to less than half), an increased market weight (to more than double), and a reduction in feed required (to less than half). These

Table 6.1 Changes in poultry performance in the US according to the National Chicken Council.

Year	Days to Market	Market Weight (kg)	Feed to Gain
1935	98	1.3	4.4
1955	70	1.4	3.0
1975	56	1.7	2.1
1995	47	2.1	1.95
2015	48	2.8	1.89
2018	47	2.9	1.82

changes predominantly reflect tremendous genetic improvement through selection. There have also been great improvements in egg production (see Table 6.2).

Breeding of poultry differs from the breeding of other livestock animals. First, the breeding program is based on pedigree and/or grandparent or great-grandparent lines. These are subjected to intensive selection. Second, there is a much larger number of generations that have been subjected to the intensive selection due to very rapid reproduction. Third, breeding/genetics is predominantly concentrated in a few large international companies.

For today's poultry production, closed pedigree lines are subject to intense selection. From these, great-grandparent and grandparent lines are derived. These lines may be crossed to give parent lines that are in turn crossed to produce the broiler chicks, pullet chicks, or turkey poults. The broiler chicken industry takes advantage of hybrid vigor, or heterosis, to increase growth rate.

In developing high-performing genetic stocks, breeders have applied quantitative population genetics together with inbreeding, hybridization, genomics, and other techniques. Commercial breeding requires excellent beginning stock (germplasm), scrupulous recordkeeping, and the application of population genetics, statistics, and computing to evaluate genetic stocks and progress from selection. Commercial breeding of poultry has three objectives: (1) Increased product output per bird (or unit space); (2) increased efficiency of production per unit feed; and (3) improved quality of the product (e.g., increased breast muscle yield in broiler chickens) and disease resistance.

For broiler chickens, turkeys, and ducks, the major indices are improvements in growth rate and feed conversion. For layer chickens, the major indices are egg production and feed conversion. In addition, improvements in the following are desirable: fertility, hatchability, body conformation, meat (particularly breast) yield and quality, egg size and quality, and livability.

Table 6.2 Changes in egg production in the United States.

Year	Number of Eggs per Hen per Year	Mortality
1920s	100	~40
2015	265	< 5

Data from the United Egg Producers.

TEXTBOX 6A

A Deeper Dive: The Impact of Genetics on Broiler Chickens and Turkeys

Tremendous progress has been made in improving the genetics of broiler chickens and turkeys (Textbox 6A Table 1).

The impact of genetics has resulted in the following:

- 4.6-fold increase in growth rate in chickens as indicated by body weight at 42 days old.
- 2.2-fold increase in growth rate in turkeys as indicated by body weight at 112 days old.
- 51-point improvement in feed conversion in broiler chickens.
- 30-point improvement in feed conversion in turkeys.
- 74% improvement in breast weight as a percentage of body weight in broiler chickens.
- 23% improvement in hatchability.

It should be noted that improvements in poultry nutrition (see Chapter 7), incubation, and health have also made strong contributions to the success of poultry production.

Textbox 6A Table 1 Impact of improved genetics on chickens and turkeys.

		Random-bred	Commercial
Chickens[a]	Body weight at 42 days (kg)	0.58	2.67
	Feed conversion (0 to 42 days)	2.14	1.63
	Pectoralis (breast) weight (% of body weight)	11.5	20.0
Turkeys[b]	Body weight at 112 days (kg)[c]	5.5	12.0
	Feed conversion (0 to 112 days)	2.63	2.33
	Hatchability (%)	55.8	68.4

[a] Randombred 1957 and commercial 2001 broiler chickens
[b] Randombred 1966 and 2003 commercial turkeys
[c] Approximate market weight

Data from Havenstein et al., 2003a; b; 2007.

6.2 Genes, DNA, and Chromosomes

Animals and plants are made up of millions of microscopic cells. Each cell has a nucleus containing the chromosomes and multiple mitochondria, with both chromosomes and mitochondria containing deoxyribonucleic acid (DNA). There are some genes in the energy-producing organelles of the cell, the mitochondrion (plural, mitochondria). This is mitochondrial DNA. The chromosomes, together with the mitochondria, contain the full genetic makeup, or genome, of the animal or plant.

Chromosomes are composed of chromatin. In turn, chromatin is made up of DNA wrapped around specific proteins, e.g., histones, together with RNA. There are two forms of chromatin—euchromatin and heterochromatin. Euchromatin is somewhat condensed and allows transcription, and heterochromatin is highly condensed and normally does not allow transcription. Genes determine the development, functioning, and characteristics of poultry (e.g., growth rate or feather color) as they do in all animals and plants. Genes, composed of DNA, are predominantly present in paired chromosomes (and therefore paired genes); the rest being in the mitochondria. In the body cells of an animal or plant, chromosomes are present as a pair of duplicates. This is known as the diploid situation.

One of each pair of both genes and chromosomes comes from the gametes (spermatozoa and ovum) from each parent. In the formation of the gametes, the ovum (egg) and the spermatozoa (sperm), a reduction division (meosis) occurs and half the number of chromosomes and genes goes into each gamete. The nuclei of the gametes are haploid with one set of chromosomes and of genes. Thus, each gene maintains its identity generation after generation. When mating and fertilization occur, the single chromosomes from the gamete from each parent unite to form new pairs, and the genes are again present in duplicate (diploid) in the embryo's cells. Under Mendelian genetics, there are paired genes that segregate in the gamete and associate following fertilization (see Figures 6.1 and 6.2). One gene of a pair of genes may be silenced.

Deoxyribonucleic Acid (DNA)

In recent years, our knowledge of the functioning of DNA has expanded tremendously with the development of the fields of molecular biology and genomics. Deoxyribonucleic acid (DNA) encodes the genetic information in animals, plants, bacteria, and many viruses. DNA consists of long sequences of four nucleotides: adenine (A), guanine (G), cytosine (C), and thymine (T). The genetic code is based on triplet sequences of these four nucleotide bases with each triplet or codons coding for specific amino acid residues together with triplets for start or end of protein. **Regulatory sequences** are DNA sequences that control the functioning of the gene. These DNA sequences regulate expression of RNA from the DNA. Expression is increased or decreased by the binding of regulatory proteins (transcription factors) to regulatory sequences in the DNA. The DNA is duplicated and copied during cell division so that daughter cells get the full genetic code. DNA gets expressed and translated to make proteins that control the functioning of a cell; determine the basic morphology of the cell, organ, and body; and control development (cell division and differentiation) and thereby dictate the

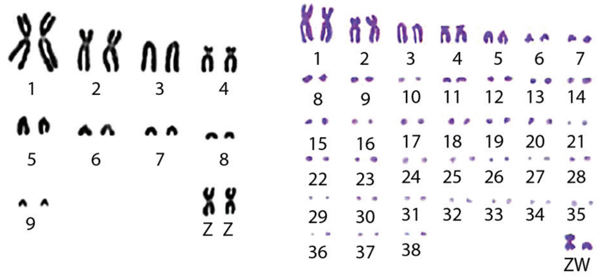


Figure 6.1 Conceptual view of chicken chromosomes.

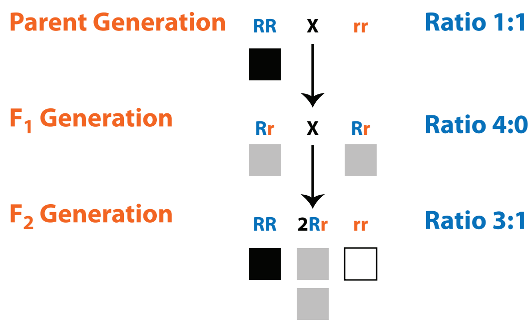


Figure 6.2 The inheritance of the pair of characteristics in chickens: R (dominant rose comb) and r (recessive single comb). The possible gene pairs or genotypes are RR, Rr, and rr. The possible phenotypes shown are either rose comb (a solid square) or single comb (an open square).

TEXTBOX 6B

Critical Events in the History of Poultry Genetics

Mendel and Genetics

Gregor Mendel (1822–1884) was a monk who lived in what is now the Czech Republic (Czechia). He experimented with pea plants (e.g., flower and seed color, shape, height, etc.). Based on the evidence of experimental results, Mendel proposed what are effectively the laws of genetics; that an organism has a pair of alleles and these segregate in the gametes and re-associate independently (see Figure 6.1). He is viewed posthumously as the father of genetics.

Dates in the Discovery of DNA

1869: Nuclein (later recognized as deoxyribose nucleic acid or DNA) was first isolated from human white blood cells (in pus) by Johannes Miescher, a Swiss physician. He later linked it to heredity.

1953: The double helix structure of DNA was established in a paper from James Watson, an American biologist, and Francis Crick, a British physicist, based on x-ray images produced by Rosalind Franklin, a British chemist/crystallographer. This was recognized with the Nobel Prize for Physiology in 1962 to Watson, Crick, and Maurice Wilkins (Rosalind Franklin's supervisor). Rosalind Franklin had died in 1958 and, as Nobel prizes are only awarded to people who are alive, she unfairly did not get one.

Late 1950s and 1960s: Development of the central dogma of molecular biology (Crick, 1970).

Dates in Poultry Genetics

1902–1909: Bateson and Punnett were the first to demonstrate Mendelian genetics in any animal species. They used chickens as the experimental model, employing comb type as the phenotype (see Figure 6.2).

2004: The draft sequence of the chicken genome was published.

2000s: Epigenetic effects in poultry increasingly recognized, with genome-wide review published in 2017 by David and colleagues.

entire process by which a group of cells become an organ and how a fertilized ovum becomes a chicken, a cow, or a human. The genes and DNA are mainly present in the chromosomes.

Central Dogma of Molecular Biology

Proteins are produced from specific sequences of DNA encoding them in a two-step process.

1. **Transcription**. The transcript, **ribonucleic acid (RNA)**, is produced, using DNA as the template, by the enzyme RNA polymerase. This RNA is processed to form **messenger RNA** (mRNA). The transcript is made up of sequences of RNA called introns and exons. The RNA is processed by clipping out the introns, leaving mRNA composed of a sequence of exons.
2. **Translation**. The mRNA is used as a template for the synthesis of proteins with specific amino acids. This is known as translation. This system is summarized below:

Transcription *Processing* *Translation*
DNA → RNA → mRNA → Protein
Expression

Some proteins can be chemically changed in what is called post-translational modification, such as clipping out an important peptide.

Definitions

Epigenetics

Epigenetics is the study of the chemical modification of genes that thereby influence their functioning. This change can be transmitted to daughter cells in cell division and/or the next generation of animals. This is inheritance in addition to DNA sequence. Examples of epigenetic changes are methylation of DNA and either methylation or acylation of histones.

Mitochondrial DNA

Mitochondrial DNA (mtDNA) is only inherited from the mother, the hen. The DNA is haploid (only one copy of the gene) with characteristics distinctly different from chromosomal DNA; it has a lack of recombination and a high mutation rate. Genes present in mitochondrial DNA are related to oxidative phosphorylation in the mitochondrion such as the NADH dehydrogenase subunit IV.

6.3 POULTRY GENOME AND CHROMOSOMES

In birds, there are two distinct sizes of autosomal chromosomes: (1) chromosomes or macrochromosomes and (2) microchromosomes. This is unlike the situation in mammals. Both macrochromosomes and microchromosomes contain multiple genes. Each chromosome is typed with special DNA called the telomere.

TEXTBOX 6C

A Deeper Dive: Epigenetics

Heredity is not solely due to the sequence of nucleotides in DNA. In addition, the DNA can be chemically modified (e.g., methylated) to reduce or increase expression from the gene or even silence it. This is epigenetics.

Epigenetics is a molecular mechanism involved in the regulation of gene expression that is reversible and heritable (by mitosis and potentially meiosis) without alteration of the DNA sequence. Berger and colleagues (2009) defined an epigenetic trait as “a trait with a stably heritable phenotype resulting from changes in a chromosome without alterations in the DNA sequence” with “the heritability of a phenotype, passed on through either mitosis or meiosis.” Epigenetic changes can be transmitted to daughter cells in mitosis (cell division). In addition, there can be transgenerational epigenetics. During both early embryonic development and the production of germ cells/gametes, there is removal of methylation of DNA followed by methylation. However, some DNA can remain methylated and, therefore, be transmitted to the next generation. Epigenetic effects are also seen when histone proteins have been chemically modified influencing gene expression. There is increasing evidence of epigenetic effects in poultry (see David et al., 2017).

1. The chicken genome has 39 pairs of chromosomes:
   - Macro or large (autosomes) (5 pairs).
   - Intermediate (autosomes) (5 pairs).
   - Micro or small (autosomes) (28 pairs).
   - The sex chromosomes—ZZ in males and ZW in females with gender determination by dosage of the Z-linked transcription factor gene and other genes (in contrast in mammals the sex chromosomes are XY in males and XX in females).
2. The turkey, partridge, pheasant, and emu genomes have 41 pairs of chromosomes.
3. The domestic duck, Muscovy duck, and domestic goose genomes have 40 pairs of chromosomes.
4. The pigeon, ostrich, and rhea genomes have 40 pairs of chromosomes.
5. The Japanese quail genome has 39 pairs of chromosomes.

The number of chromosomes is much higher in birds than in mammals (cats and pigs have 19 pairs, humans have 23 pairs, sheep have 27 pairs, cattle and goats have 30 pairs, horses have 32 pairs, donkeys have 31 pairs, and dogs have 39 pairs). Autosomes (chromosomes that are not sex chromosomes) are numbered in descending order by size (i.e., the largest is chromosome 1, the next largest is chromosome 2, etc.). The sex chromosomes are not numbered but called Z and W in birds.

Size of Genome

There has been tremendous progress determining the sequence of poultry genomes. The genome of chickens has been sequenced. It is relatively small but gene-rich genome with over 20,000 genes. There are 1.2×10^9 (1.2 billion) base pairs per haploid genome in chickens. There is also a well-developed genomic map for the chicken. Similarly, the genome of turkeys, ducks, and geese have been characterized. There are 23,044 genes in domestic ducks. Moreover, significant progress has been made in sequencing the ostrich genome.

6.4 The Bases of Genetic Improvement in Poultry

Genetic Variation

Much of the genetic variation between individuals is due to point mutations, called single nucleotide polymorphisms (SNPs) together with deletions and insertions of part of a gene or the upstream or downstream sequences. About 140 million SNPs have been detected in populations of chickens. These variations also influence the nucleotide sequence in RNA and the structure of proteins or control expression.

Poultry geneticists/breeders use the genetic variation and the techniques of population genetics to improve chickens, turkeys, and ducks. It is reasonably easy to see that geneticists have to contend with the fact that there can be different genotypes for the phenotype and there can be profound interactions between genotype and environment. Genetic gain is accomplished by progeny-testing and sib- or half-testing; sibs being siblings (brothers or sisters).

Much of the early research on poultry genetics used color as the end point. Multiple genes control the feather color in chickens and turkeys (for details see Textbox 6D). Most traits of economic interest are multiple genes (> 30 for growth). Selection may be assisted by **quantitative trait loci** (QTL) or candidate genes. QTL have been identified from crosses of layer and meat lines.

TEXTBOX 6D

Traits under Simple Mendelian Genetic Control in Chickens

I. Autosomal
Examples of autosomal genes include of the following:
A. Feather Color
1. Dominant white locus (chromosome 2)
   a. I dominant white (inhibitor of black) seen in White Leghorn and Hamburg breeds of chickens.
   b. Dun
   c. Smoky (recessive) partially restoring pigmentation
2. E locus (Micro chromosome 11). The E locus has multiple alleles including the following (in order of dominance):
   a. E*E—extended black
   b. E*R—birchen
   c. E*WH—dominant wheaten
   d. E*N—wild type
   e. E*B—brown
   f. E*BC—buttercup
   g. E*Y—recessive wheaten (yellowish-white).

B. Other Mendelian Genes on Autosomal Chromosomes
1. Rose comb locus (chromosome 7)
   a. RR—rose comb
   b. Rr—rose comb (dominant in heterozygous)
   c. Rr—single comb
2. Skin color (yellow or white). W locus with alleles (on chromosome 3) for respectively yellow and white skin. The alleles are the following:
   a. WW with the phenotype of white skin
   b. Ww with the phenotype of white skin in heterozygous state (WW dominant)
   c. ww with the phenotype of yellow skin (recessive)

II. Sex-Linked Traits
A. Color of Plumage
1. Examples of sex-linked genes include of the following:
   a. Sex-linked Silver gold locus. There are the following alleles on the Z chromosome (males ZZ; females ZW):

   Males:
   (1) *SS* Silver) incompletely dominant with production of pheomelanin inhibited
   (2) *SN* (wild type/gold)
   (3) *S*AL* (sex-linked imperfect albinism)
2. Sex-linked barring
   a. There are the following alleles on the Z chromosome (males ZZ; females ZW):

   Males:
   (1) *BB* Sex-linked barring with a pattern of wide bars (horizontal stripes) with lack of pigment (partially dominant).
   (2) Bb^+ with a pattern of narrow bars with lack of pigment (gene dosage effect in heterozygous).
   (3) b^+b^+ (Wild type—recessive).

   Females:
   (1) *B-* with a pattern of narrow bars with lack of pigment (gene dosage effect)
   (2) b^+- (wild type—recessive)

B. Other Mendelian Genes on Z Chromosome
1. Rate of feathering. This is used for sexing chicks.

   Males:
   a. *KK* Late or slow feathering (K late feathering, K^s slow feathering and K^n very slow feathering)
   b. Kk^+ Late or slow feathering (dominant)

   Females:
   (1) *K-* Late or slow feathering
   (2) k^+- Rapid feathering (recessive)

   Thus, crossing k^+- (female) with KK (male) will always result in rapid feathering in female chicks and slow feathering in male chicks.
2. Sex-linked dwarfism. There are the following alleles on the Z chromosome (males ZZ; females ZW):

   Male:
   a. *DwDw*—No dwarfing
   b. *Dwdw*—No dwarfing (Dw dominant)
   c. *dwdw*—Dwarf

   Females:
   a. *Dw*—No dwarfing
   b. *dw*—Dwarf
3. Brown egg shell

   Females:
   a. *Pr*—brown egg
   b. *pr*—white eggs as synthesis of brown pigment production is inhibited.

In addition, genes may be introgressed from other populations of the same species of poultry. This differs from the procedures of transgenics (discussed in Chapter 1). Transgenics is the transfer of a gene or series of genes from one organism (animal, plant, bacteria) or a synthetic gene(s) to another organism often of a different species. Opponents of transgenics or genetically modified organisms (GMOs) raise the issues of (1) food and environmental safety (DNA spreading from transgenic animals or plants to wild species with unexpected consequences) and (2) the moral responsibility of tampering with nature (removing nature's evolutionary barrier between species that do not mate). It is unlikely that transgenic chickens will be used in commercial poultry production in the foreseeable future. Nevertheless, poultry scientists should keep abreast of new developments in this exciting new field.

Growth rate is highly heritable and has been markedly improved by selection. It is estimated that poultry geneticists have been responsible for over three-quarters of the improvement in the efficient production of broiler meat. Egg production and hatchability have relatively low heritabilities. However, intensive selection has enabled considerable advances in these characteristics.

Dominant and Recessive Genes

Since animals are diploid, there are two copies of genes, or alleles, but with allelic variation. Genes may be recessive (not expressed) (aa = o); additive (both expressed equally ($a + A$) or incomplete dominance; dominant (expressed) ($AA = Aa$); or overdominant (more expression if with recessive genes) ($Aa > AA$).

Simple Gene Inheritance (Qualitative Traits)

In the simplest type of inheritance, only one pair of genes is involved. Thus, a pair of genes is responsible for comb type, plumage color, and skin color. Figure 6.2 shows the inheritance of a two comb types. For example, this could be the result of mating a rose-comb White Wyandotte male and a single-comb White Plymouth hen (comb types commonly found in chickens). An R is used as the symbol for the rose-comb gene because it is dominant to the single-comb gene; an r is used as a symbol for the recessive single comb.

Multiple Gene Inheritance (Quantitative Traits)

Relatively few characters of economic importance in poultry are inherited in as simple a manner as comb type. Commercially important characters such as egg production, growth rate, and feed efficiency are due to multiple genes; thus, they are called multiple-gene characters. Because these show a gradation from high to low, they are viewed as quantitative traits. Quantitative traits are of particular interest to poultry breeders to improve the average performance of a flock in several quantitative characters at the same time.

Some genes have the ability to prevent or mask the expression of others, with the result that the genetic makeup of such animals cannot be recognized with perfect accuracy. This ability to cover up or mask the presence of one member of a set of genes is called dominance. The gene that masks the other one is the dominant gene; the one that is masked is the recessive gene. The recessive gene may be economically advantageous. Alternatively, there may be cases of overdominance where the maximal effect is observed in the heterozygous state. Some dominant and recessive characteristics in chickens are listed in Textbox 6D. Many alleles exhibit additivity (incomplete or partial dominance) so that it is possible to distinguish the heterozygous individuals as well as both types of homozygote.

There are varying degrees of dominance. In the vast majority of cases, dominance is incomplete or partial. Also, it is now known that dominance is not the result of single-factor pairs, but that the degree of dominance depends upon the animal's entire genetic makeup together with the environment to which it is exposed, and the various interactions between the genotype and the environment.

6.5 Inheritance of Important Traits in Poultry

Phenotype is controlled by both genotype and environment. For example, a hen may have genes that allow her to lay 300 eggs a year, but if she is not fed properly, given good housing, and protected from disease, this will not occur. The inheritance of some important characters in poultry follows.

- **Plumage color**. White feathers can be important to broiler chickens because of ease of plucking and clean appearance. Similarly, white turkeys and white ducks are preferred (see Textbox 6D).
- **Skin and shank color**. Yellow shanks are due to carotenoid pigments in the epidermis and the absence of melanin pigment. Black shanks are due to the presence of melanin in the epidermis. White shanks are due to the absence of both pigments (see Textbox 6D).

- **Rate of feather development.** Early or late feathering is used to sex chicks (see Textbox 6D).
- **Color sexing.** The sex of baby chicks can be identified by silver (white) versus gold (red) down colors (see Textbox 6D).
- **Blood groups.** Blood-group information can be useful in detecting pedigree errors. Genetic fingerprints are, however, now preferable.
- **Egg production.** Greater efficiency of egg production can be achieved through selection (discussed below). Broodiness has been greatly reduced in laying chicken breeds but is still present in turkeys and bantum chickens, along with broiler chickens to a limited extent.
- **Broiler chickens** are selected for body weight (60% heritability), growth rate (35% heritability), and feed efficiency.

TEXTBOX 6E

A Deeper Dive: Molecular Basis of Plumage Color

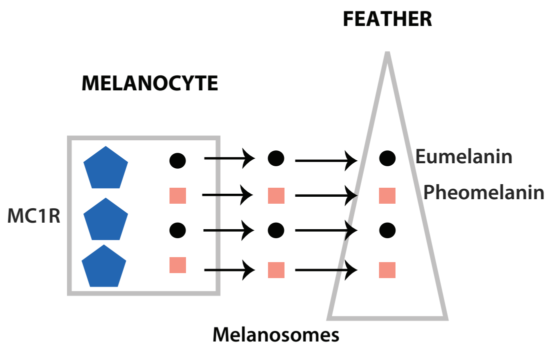
Textbox 6E Figure 1 shows the melanocytes exporting pigmented melanosomes to the skin and to the developing feathers in the follicles. There are two pigments, eumelanin (black) and pheomelanin (red/brown). The precursor of eumelanin is tyrosine, with the tyrosinase playing a critical role. This synthesis is under the control of MC1R by melanocytes. A ligand for MC1R is melanocyte-stimulating hormone (MSH). In mammals, keratocytes express POMC (pro-opiomelanocortin), the precursor of MSH. Agouti-signaling protein is also produced locally and binds to the MC1R; but acting as an antagonist. MSH and MC1R induces production of eumelanin (black). In contrast, agouti-signaling protein stimulates the synthesis of pheomelanin (red/brown) and inhibits production of eumelanin. This protein is responsible for color dichromatism between males and females with males having brilliant plumage (Oribe et al., 2012).

The genetic basis of plumage color has been related to genes specifically expressed in melanocytes:

- **Dark brown:** The dark brown plumage has been related to a deletion upstream of SOX10 (Gunnarsson et al., 2011). The neural crest transcription factor, SOX10, is a marker for melanocytes but is also expressed in Schwann cells (in the nervous system) and bronchial myoepithelial cells (Nonaka et al., 2008).
- **Dominant white:** The dominant white allele is due to polymorphisms in the gene PMEL17 (Kerje et al., 2004). The gene PMEL17 encodes a melanocyte specific glycoprotein that plays an important role in the formation of melanosomes (Berson et al., 2001). The melanosomes carry packages of melanin to the skin or feathers. Therefore in the presences of the defect in the PMEL17 gene there will be a lack of melanosomes and hence color.
- **E locus:** The various alleles of E locus is thought to be due to polymorphisms of MC1R gene (melanocortin 1 receptor) (Kerje et al., 2003). MC1R is a gene known to control the synthesis of melanin by melanocytes.
- **Lavender color dilution:** A mutation in the MLPH gene is responsible for the lavender color dilution in chickens (Vaez et al., 2008). The MLPH gene is transcribed and translated to form melanophilin, a protein involved in the transport of melanosomes.
- **Silver locus:** The silver allele on the silver locus is due to a mutation in the SLC45A2 gene encoding solute carrier family 45, member 2, protein (Gunnarsson et al., 2007). This protein is important in sorting vesicles in melanocytes.

Textbox 6E Table 1 Colors of plumage.

Pigment	Color
Eumelanin	Black
Phaeomelanin	Yellow/Red/Brown



Textbox 6E Figure 1 A model for melanocytes synthesizing pigments; in this example melanin as eumelanin (black) and pheomelanin (yellow/red/brown). The melanin is packaged in melanosomes and exported to the skin or feathers, giving them their color. The MC1R (melanocortin 1 receptor) plays an important role in determining how much and which melanin is produced.

- **Reduced mortality.** Viability or livability is greatly influenced by feeding, husbandry, and vaccinations. Chickens show genetic and family differences in resistance or susceptibility to diseases. Hence, poultry geneticists have concentrated on developing strains of higher livability. The possibility of developing genetically resistant strains has been demonstrated; resistant lines showed 2–3% mortality from leukosis, while susceptible strains had 25% mortality.

6.6 Other Aspects of Poultry Genetics and Genes

Mutations, Deletions, and Insertions

Gene changes are known as mutations. A mutation may be defined as a sudden variation that is later passed on through inheritance and that results from changes in a gene or genes. Mutations are not only rare but are also predominantly harmful. However, mutations provide the "raw material" for breeders to work with.

Lethal Genes and Abnormalities of Development

Lethal genes are congenital abnormalities that result in the death of an animal, most frequently during embryonic development. Other defects occur that are not sufficiently severe to cause death but that do impair the usefulness of the affected animals. Many such abnormalities are hereditary, being caused by certain "bad" genes. All lethal genes are recessive and may remain hidden for many generations. The prevention of such genetic abnormalities requires that the breeding birds be purged of the "bad" genes.

Inbreeding

As practiced by the poultry breeder, inbreeding is the mating of closely related individuals, such as brother to sister, for successive generations. The procedure of developing inbred lines and forming hybrids was borrowed from hybrid corn breeders. Inbreeding is used in poultry to develop pedigree lines which, when crossed, will give progeny high egg production, large eggs, good meat type, and good livability. The steps in developing inbred hybrids are (1) the formation of inbred lines by intensive inbreeding and selection and (2) the screening of crosses (hybrids) of inbred lines.

Factoids

Origin of Commercial Egg Layers

- Origin of white-egg layers—White Leghorns
- Origin of brown-egg layers—the dual-purpose American breeds, Rhode Island Red and White Plymouth Rock

Origin of Broiler Chickens

- Male—Cornish (compact bodies with high proportion of breast muscle)
- Females—dual-purpose American breeds such as Barred Plymouth Rock, White Plymouth Rock, and New Hampshire

Genetic diversity has been reduced due to the relatively small numbers of breeds underlying modern poultry production. However, the Cornish, Plymouth Rock, and New Hampshire breeds are themselves all derived from multiple breeds. For discussion of the origin of breeds such as Cornish, New Hampshire, Rhode Island Red, White Leghorn, and White Plymouth Rock see Appendix I.

Heterosis

Heterosis (hybrid vigor) is a name given to the biological phenomenon that causes crossbreds to outperform the average of their parents. For numerous traits, the performance of the cross is superior to the average of the parental lines. Heterosis is used in many breeding programs. The first major example is hybrid seed for corn/maize (developed inbred lines are crossed). This approach is used extensively in commercial poultry production. The basis for heterosis is still not fully understood. It may involve over-dominance and/or masking the effects of unfavorable recessive genes. Heterosis is measured by the amount that the crossbred offspring exceeds the average of the two-parent inbred lines for a particular trait, using the following formula for any one trait:

$$\text{Percentage hybrid vigor} = \frac{\text{Crossbred average} - \text{Parent average} \times 100}{\text{Parent average}}$$

The level of hybrid vigor for all traits depends on the lines crossed. The greater the genetic difference between two lines, usually the greater the hybrid vigor expected.

Hybrid Vigor or Heterosis

Hybrid vigor follows outbreeding (i.e., cross breeding two inbred lines). This is where the specific characteristics of the offspring are superior to both parents or parent lines. The opposite of hybrid vigor is inbreeding depression.

6.7 Poultry Breeding

Types, Breeds, and Classes of Chickens

Type refers to the general shape and form, without regard to breed. Chickens are of three types: (1) the meat type, bred for meat production; (2) the egg type, bred for egg production; and (3) exhibition chickens, bred for show. The term *class* designates groups of breeds developed in certain regions; hence, the class names: American, English, Asiatic, and so on (breeds and varieties of poultry are covered in Appendix I).

Broiler Production

Broiler poultry meat comes from broiler chickens that are slaughtered at 6 to 8 weeks old (see Chapter 19). Depending on markets or further processing, chickens may be processed at lighter or heavier weights. In order to grow rapidly to market weight, the parents of broiler chickens have become very large. Broiler breeder hens produce fewer eggs than layer hens, with lower peak of production and shorter duration of lay (see Section 6.9 for examples of primary breeder and names/trademarks of broiler chicks).

Egg Production

Chickens bred for egg production must be small-bodied (and hence a lower basal metabolic rate). They consume lower amounts of feed while producing a large number of eggs. Hens laying whiter eggs weigh less than 3.5 lb (< 1.6 kg) and about 4 lb (1.8 kg) for brown-egg producers. Excellence in egg-type chickens is evaluated by the average egg number per bird, egg size, egg quality, and feed efficiency. Layer pullets are sold under a breeder's trademark name (see Section 6.9 for examples of primary breeder and names/trademarks).

Genetics and the Colors of Eggs

White eggs are the absence of pigment and brown eggs are colored due to the deposition of protoporphyrin IX (together with some biliverdin) between the calcium carbonate crystals by the shell gland. Blue egg shells (in the breed Araucana) contain the pigment oocyanin, a by-product of bile production.

The color of eggs is controlled in part by the breed/genetics of the chickens with much higher levels of synthesis of protoporphyrin IX in brown-egg laying chickens (see Textbox 6C). There are also environmental effects on egg color with lighter brown color at the beginning of lay. Moreover, when laying hens receive the coccidiostat drug nicarbazin, the eggs lose coloration. The blue coloration is also controlled by a simple allele.

6.8 Breeds and Varieties

What Are a Breed and a Variety?

The specific "standards of excellence or perfection" of each breed/variety are detailed in a publication entitled *Standard of Perfection*, published by the American Poultry Association (APA). The term **breed** refers to an established group of domestic poultry possessing a distinctive shape, plumage, skin colors, and the same general weight. Breeding is restricted to members of the same breed and variety, and hence called purebreds.

A **variety** is a subdivision of a breed, distinguished either by color, color and pattern, or comb. Hence, a breed may embrace a number of varieties, distinguished by different colors (e.g., white, black, buff, etc.); or by color/markings (e.g., Light Brahma, Dark Brahma, etc.); or by different combs (single comb, rose comb, etc.). Breeds/varieties of chickens, turkeys, ducks, and geese are discussed in detail in Appendix I. The initial objective of the APA was to standardize the breeds and varieties of domestic birds shown in exhibitions. While there is little interest in purebreds by commercial poultry breeders, purebred chickens are raised by enthusiasts who show them in exhibitions.

There is increasing interest in some breeds of chickens and turkeys as heritage breeds/varieties (discussed in Chapter 3). It should be noted that when there are very few of some of the rarer breeds/varieties, there may be problems of fertility, poor egg production, and hatchability. There are risks from inbreeding, including congenital problems and lack of vigor. Various breeds were the basis of modern commercial chickens:

- Broiler inbred lines and hence broiler chickens developed from predominantly two breeds, (1) White Plymouth Rock and (2) Cornish.
- Layer lines producing white eggs were from White Leghorns while those producing brown eggs came from Rhode Island Reds. (The Golden Comet is a cross between a Rhode Island Red and White Leghorn chicken.)

6.9 Organization of Commercial Poultry Breeding

Commercial chicken producers are either egg producers or broiler producers. For either, it is net return that counts. The commercial producer is interested in increasing product output per bird, the efficiency of production, and the product quality. Improvements in fertility, hatchability, growth rate, body conformation, egg yield, meat yield, feed conversion, egg quality, meat quality, and viability contribute to profitability. The poultry industry is an exemplar of incorporating science and technology. Hand in hand with the transformation of the poultry industry, a very high degree of specialization has developed. From a breeding standpoint, today's poultry breeding is centered in three types of enterprises: (1) the primary breeder, (2) the broiler breeder or multiplier, and (3) hatcheries.

Poultry breeding follows a breeding pyramid (see Figure 6.3). At the top of the pyramid are the pedigree or elite lines. These are under intense selection by primary breeders. The progeny of the pedigree lines can go in one of three directions: (1) back to the pedigree lines, (2) great-grandparent or grandparent lines, and (3) culled.

There can be two-line crosses, three-line crosses, and four-line crosses. Lines used for crossing must "nick" or complement each other. The offspring of the grand lines will be the parents of replacement pullets or of broilers (broiler breeders) or turkey poults from meat production.

Primary Breeders

Primary breeders are large, well-managed international companies. The goals of breeding programs are generally the maximization of genetic gain and the minimization of inbreeding.

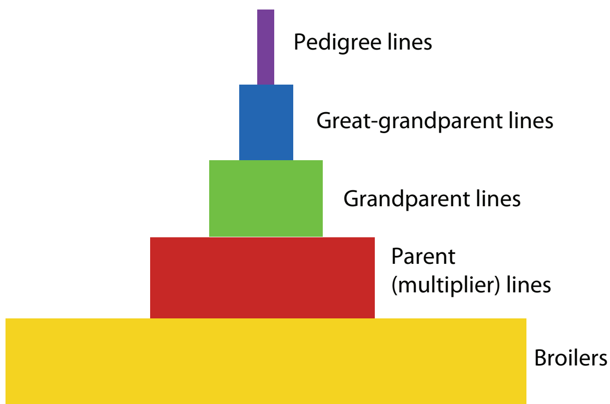


Figure 6.3 The breeding pyramid in broiler production. The primary breeders have pedigree birds undergoing selection, these produce great-grandparent lines and grandparent lines. These are crossed to produce the parent lines of broiler breeders.

What Are Microsatellites and How Are They Used?

Microsatellites are sequences of DNA with motifs (2–5 nucleotides long) repeated multiple (5–50) times. Elite line identity can be confirmed by microsatellite analysis.

Breeding companies apply genetic selection to purebred lines. Multiple traits are selected for "multitrait breeding." More recently the approach has shifted to "balanced breeding" to incorporate issues such as bird well-being. These approaches use careful monitoring of the characteristics of the bird followed by selection pressure and complex mathematics to achieve the most desirable grandparents in the inbred lines. There is subsequent multisite multiplication and crossing of the inbred lines. The crossing takes advantage of the phenomenon of "hybrid vigor." Breeding companies undertake balanced breeding programs. Selective breeding can result in negative consequences such as depressed health or well-being. This is now being addressed by breeding companies.

Breeding companies do not exchange their purebred lines. Breeding companies own (1) pedigree purebred stock, (2) grandparent lines, and (3) great-grandparent lines. Major primary breeders of poultry include the following:

- Chickens (meat or broiler)
  - —Aviagen (brands Arbor Acres, Hubbard, Indian River, and Ross) is part of the EW Group GmbH; a holding company based in Visbek, Niedersachsen (Lower Saxony), Germany.
  - —Cobb Vantress (a division of Tyson Foods with the brand Cobb).
- Chickens (slower growth specialty types):
  - —Aviagen (Rowan Range).
  - —Cobb Vantress (Sasso).
  - —Hendrix Genetics (brand Caringa—traditional poultry).
- Chickens (layers):
  - —Hy-Line is part of the EW Group GmbH; a holding company based in Visbek, Niedersachsen (Lower Saxony), Germany.
  - —Hendrix Genetics—brands: ISA, Shaver, Hisex, Dekalb, Bovans, and Babcock.
  - —Novogen (layer genetics division of Groupe Grimaud).

- Turkeys:
  - — Aviagen (brands Nicholas and BUT [British United Turkeys]).
  - — Grimaud Frères Sélection.
  - — Hybrid Turkeys (the turkey breeding division of Hendrix Genetics).
- Ducks and geese:
  - — Cherry Valley Farms (a subsidiary of Faccenda Foods Ltd).
  - — Groupe Grimaud.
  - — Maple Leaf Farms.
- Guinea fowl: Groupe Grimaud (Galor).

The primary breeders of poultry are international businesses operating throughout the world. They have well-recognized copyrighted trade and brand names.

The professionals within the primary breeders include outstanding geneticists and computer specialists; veterinarians, including pathologists; and nutritionists. The level of biosecurity increases as we move up the breeding pyramid (see Figure 6.3). In the case of broiler chickens, the primary breeder sells parent-line broiler breeders derived from grandparent stock or uses the parent line in-house to produce the chicks destined to become broilers. With hens laying table eggs, either the parent line or the commercial line is sold as chicks.

TEXTBOX 6F

Genetic Goals

Goals for genetic selection of meat-type (broilers) birds include the following:

- Production traits
  - Growth rate
  - Breast yield
  - Feed conversion efficiency
- Health and well-being traits
  - Survival and fitness
  - Absence of foot and leg defects
  - Bone quality and strength
  - Heart and lung capacity

Goals for genetic selection of laying birds include the following:

- Production traits
  - Egg production
  - Feed conversion efficiency
  - Egg shell quality
- Health and well-being traits (e.g.)
  - Hardiness
  - Bone quality/minimizing osteoporosis

Primary breeders may contract out the maintenance of pedigree and/or grandparent flocks. A business model may become the contracting out of even the ownership of the pedigree flocks but retaining control of the breeding program and improving the genetics. It is possible to envision breeding companies as information technology companies.

Ethics and Breeding Companies

Breeding companies include ethical, welfare, and behavioral analyses in their decision-making. For instance, is selection for growth rate and feed efficiency causing excess inactivity and lying down? Is welfare compromised for the broiler breeders or parent, grandparent, great-grandparent, and pedigree lines? European breeders and breeding companies have adopted a "Code of Good Practice for Farm Animal Breeding and Reproduction Organisations," demonstrating a tangible response to concerns such as animal welfare, health, and food safety. The responsibility for welfare does not stop at the breeder companies. The choices of hybrids to be used in broiler or egg production should take into account production and traits related to health and well-being. In addition, quality of the product (meat or eggs) is another critical factor.

Hatcheries/Multipliers (Including Broiler Breeders)

The multipliers multiply the stock supplied by the primary breeders. The hatcheries hatch the egg from the primary breeders or multipliers (see Chapters 18, 19, and 20 for details on laying hens, broiler chickens, and turkeys, respectively). The following can happen to the chicks or poults or ducklings:

1. They can be sold to producers, who then grow them out as commercial egg layers, broilers, or market turkeys.
2. Primary breeders and multipliers along with hatcheries can operate together through a single vertically integrated company that retains ownership of the chicks, poults, ducklings, etc. The day-old poultry goes to growers.

Methods of Mating

Chickens

The most common methods of mating are flock mating, pen mating, and artificial insemination. Flock or mass mating means that a number of males are allowed to run with the entire flock of hens. Better fertility may be obtained from flock mating than from pen mating. With the light-egg laying types, it is common to use one male for 15 to 20 hens. With the heavy breeds, one male is placed with each 8 to 12 hens. Young males are more effective than older. Males over 3 years old are usually not satisfactory. In pen mating, a pen of hens is mated with one male. If the birds are trap-nested and each hen's leg-band number recorded on its egg, this system makes it possible to know the parents of every chick hatched from a pen mating. About the same number of hens are mated with one male in pen mating as in flock mating but the fertility may not be as good.

Turkeys

Artificial insemination can be credited as a primary factor that has led to the rapid improvement of turkeys. It has served a twofold purpose:

- A single ejaculate can be collected and used to inseminate several females, whereas natural mating only allows the ejaculate to be used for a single female.
- Artificial insemination has permitted the selection of heavier, meatier birds. Male turkeys are so large that natural mating is difficult.

Turkey hens should be inseminated with fresh diluted semen (equivalent to 0.025 ml whole semen) per insemination. Inseminations every one to two weeks maintains maximum fertility as spermatozoa are stored in the hen in vaginal sperm storage glands.

TEXTBOX 6G

For Classroom Discussion

Has genetics achieved more in poultry than livestock? How would you evaluate this? If true, why has genetics achieved more in poultry than livestock? Points to consider:

1. What was the impact of the following?:
   - Differences in generation time?
   - Cost of holding numbers of animals?
   - Differences in the number of progeny from the male or female?
   - Is heterosis a factor?
   - Ease of handling breeding animals?
   - Incubation versus pregnancy?
   - Ease of transporting chicks from hatchery to farms?
2. Was the genetic progress due to its organization of poultry production or did progress in poultry genetics facilitate the development of systems of poultry production?

Selecting and Culling Chickens

The terms "selection" and "culling" carry opposite connotations in livestock production. In both poultry and livestock, selection aims at genetic progress. In livestock, culling refers to the removal of the least productive part of the herd or flock. It is aimed at the prevention of retrogression rather than making progress. In poultry, culling is the term for euthanizing birds exhibiting health problems.

Methods of Selection

Except for the poultry fancier, who is interested in breeds and varieties from the standpoint of Standard of Perfection, only exhibition chickens are selected on the basis of show winnings.

TEXTBOX 6H

A Deeper Dive: Poultry Genetics

The Advantages of Chickens for Genetic Studies

Siegel and colleagues (2006) consider chickens to have the following advantages in genetic studies:

1. Rich genetic diversity due to the long history of chickens following domestication, the number of breeds, varieties, lines, and number of SNPs (single nucleotide polymorphism) already detected (140 million).
2. Huge population size with over 10 billion chicks globally.
3. Breeding is easy with large pedigrees to achieve statistical power.
4. Large number of progeny for females.
5. High recombination rate: macrochromosomes 3-fold that of humans and 6-fold that of mice; microchromosomes 6-fold that of humans and 12-fold that of mice.
6. Mutation rate (see below).

What Is the Mutation Rate?

Siegel and colleagues (2006) estimate that the mutation rate is 1×10^{-9} per nucleotide (or one in a billion). Given the number of nucleotides (~1 billion pairs), there would be one mutation per gamete ($1 \times 10^{-9} \times 10^{9}$). With a population of 10 billion chickens, the number of mutations per nucleotide would be estimated as 10 ($1 \times 10^{-9} \times 10^{10}$).

Genetic Lines of Chickens with Specific Traits for Research

Lines of chickens and, to a lesser extent, turkeys, with specific traits have been developed by university geneticists over the last 70 years. These would be a great resource for today's genetic and genomic analysis, however many of these are no longer available due to budgetary restrictions.

6.10 Breeds and Breeding Turkeys

The varieties of turkeys of importance are listed in Appendix I. The Broad-Breasted White is the only variety that is commercially important. These were developed in the 1950s by first crossing Bronze and White Holland varieties and then backcrossing the second-generation white progeny to Bronze males. This procedure is repeated for several generations so that the resulting Broad-Breasted White is essentially a Bronze turkey with white feathering and broad-breasted in conformation. These birds were developed in response to processors' objections to the dark pin feathers of the Broad-Breasted Bronze.

In the case of turkeys, genetic improvements have developed fast-growing, broad-breasted birds but have left breeding populations with serious reproductive defects. There is marked sexual dimorphism with tom turkeys much larger than females. Part of this is attributed to the heavy males being clumsy, awkward, or even violent in mating. This can lead to injury to the females. For this reason, turkey breeders use artificial insemination.

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7

Fundamentals of Poultry Nutrition

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List the essential nutrients.
2. Know what energy in feed is required for.
3. Understand the definitions of commonly used energy terms.
4. Understand the importance of carbohydrates in feed.
5. Know the roles of glucose and glycogen in poultry.
6. Define starch and cellulose and explain why starch can get digested but cellulose cannot.
7. Know the lipids in poultry feed.
8. Understand the chemistry and importance of triglyceride, saturated fatty acids, and monounsaturated and polyunsaturated fatty acids.
9. Know what an essential fatty acid is.
10. Understand the importance of protein in feed.
11. List the amino acids and their basic chemistry.
12. Define indispensable, conditionally indiscernible, and dispensable amino acids, and understand the difference between indispensable versus dispensable amino acids and conditionally indispensable amino acids.
13. Define what a limiting amino acid is.
14. Define what an ideal protein is.
15. List the macrominerals and why they are required.
16. Know the consequences of a deficiency for each macromineral.
17. List the microminerals (trace elements) and why they are required.
18. Know the consequences of a deficiency for each trace element.
19. List the major fat- and water-soluble vitamins and why they are required.
20. Know the consequences of a deficiency for each vitamin.

7.1 INTRODUCTION

Poultry transforms feed into meat and eggs (see Figure 7.1). The amount of feed required to produce a kilogram (or pound) of poultry meat or a dozen eggs has decreased over the last 75 years. One of the greatest costs to poultry and livestock producers is feed. Arguably, feed is still the greatest cost in poultry production but it continues to decrease.

Understanding the principles of nutrition is important to be able to convert feed to poultry meat or eggs efficiently and economically. A key to the success of poultry production has been the application of nutritional principles to genetically superior birds raised under good management with strong animal health

Figure 7.1 Chickens eating. (Photo credit: Anastasia_ Panait/Shutterstock)

programs. Knowledge of the anatomy and physiology of the avian digestive system is critical to understanding the fundamentals of poultry nutrition. See Chapter 4 for a discussion of the gastrointestinal tract.

Nutrient Composition of Poultry and Egg

Nutrition encompasses the various chemical and physiological reactions that change feed elements into body elements. It follows that knowledge of body and egg composition is useful in understanding poultry response to nutrition. Table 7.1 shows the composition of poultry meat and eggs. Within each type of animal there is a wide range in body composition, depending on age and nutritional status. The following shifts in body composition occur:

1. **Water**. The percentage of water decreases during growth with increases in fat.
2. **Fat**. The percentage of fat increases with growth depending somewhat on feed availability.
3. **Protein**. The percentage of protein remains relatively constant during growth.
4. **Ash**. The percentage of ash shows the least change.
5. **Composition of gain**. Gain in weight does not provide an accurate measure of the actual gain in energy of the animal, because it tells nothing about the composition of gain. This is important because efficiency of feed utilization (units of feed per unit body gain) is greatly influenced by the amount of fat deposited.
6. **Species comparison**. Poultry and livestock species have differences:
   a. Poultry contain less fat as a percentage, but more water.
   b. Broiler chickens and turkeys have higher protein percentages than livestock.

TEXTBOX 7A

A Deeper Dive: The Impact of Improving Nutrition on Poultry Performance

The application of improved knowledge of nutrition has resulted in large improvements in performance of both broiler chickens and turkeys as can be seen from the data shown in Textbox 7A Table 1. Similar improvements are seen in laying hens. The result of these improvements has been lower costs of poultry production and consequently lower costs to consumers.

Textbox 7A Table 1 Impact of improved nutrition on broiler chickens and turkeys.

		Pre-1970 Diet[1]	**Post-2000 Diet[2]**	**Improvement (%)**
Chickens	Body weight at 42 days (kg)[3]	2.13	2.67	25.4
	Feed conversion	1.92	1.63	15.1
	Hot Carcass at 43 days (kg)	1.46	1.93	32.2
	Pectoralis (breast) muscle (% of body weight)	17.4	20.0	14.9
Turkeys	Body weight at 112 days (kg)[3]	10.6	12.0	13.2
	Feed conversion	2.66	2.33	12.4

[1] Turkeys 1966 diet.
[2] Turkeys 2003 diet.
[3] Approximate market weight.

Data from Havenstein et al., 2003a; 2007b.

Table 7.1 Overall composition of poultry or poultry products.

	Broiler Chicken	Turkey	Egg
Water	64	60	66
Protein[1]	19	19	13
Lipid[2]	14	19	10
Ash	4	4	11

[1] Cattle and pigs have somewhat lower percentages, 17% and 13%, respectively.
[2] Cattle and pigs have higher percentages, 26% and 34%, respectively, of lipid and consequently lower water percentages, 53% and 55%, respectively.

The chemical composition of the body varies between different organs with, for instance, high ash and low water in bones and the opposite in blood.

7.2 Classification of Nutrients

Feeds are composed of nutrients that are released by digestion and then absorbed into the body to be used by the various organs and tissues. The multiple nutrients required by poultry are classified into six categories:

1. Carbohydrates.
2. Lipids (fats).
3. Proteins.
4. Minerals (macrominerals and microminerals).
5. Vitamins (water- and fat-soluble).
6. Water.

Each of these has specific functions that will be considered below. In addition, feed provides energy to poultry through carbohydrates and/or fats and proteins.

7.3 Dietary Energy

In order to live and produce meat and egg, poultry and other animals oxidize nutrients, transforming energy to a form that can be used by the body. Sources of energy are the following:

- Carbohydrate (Glycolysis and Citric acid cycle → Energy + fats)
- Triglyceride (→ Fatty acids metabolized by β oxidation → Energy, together with glycerol)
- Proteins (→ Amino acids → energy)

Carbohydrates are the most important nutrient supplying energy and are more abundant and cheaper. Fats are next in importance, supplying energy. It is inefficient to use proteins to produce energy. Protein use to produce usable energy can occur during severe infections or nutritional deprivation, however in a production setting proteins are not used to produce energy.

The energy requirement is the amount of available energy that will provide for the following:

- Maintenance of the body (such as the heart pumping blood, skeletal muscles moving air through the lungs, functioning of nerves, endocrine cells, and the gastrointestinal tract).
- Maximal growth (e.g., energy required to synthesize muscle proteins) or egg production (e.g., energy required to synthesize egg proteins and fats).

Table 7.2 summarizes the energy requirements of poultry using both requirements published some time ago by the National Research Council (NRC). This is based on published scientific research and expert opinions. In addition, some industry recommendations are included. It is cautioned that industry recommendations will change with differences in poultry lines and with genetic improvements over time. It is clear that industry energy recommendations are higher.

A lack of energy will slow growth or reduce egg production but is not associated with specific signs like those seen with mineral or vitamin deficiencies. For this reason, energy deficiencies may go undetected. The metabolic rate of poultry is an indication of the energy needs of the bird. Several factors can affect this rate, including the following:

1. **Body size**. As poultry grow, their energy requirement per unit body weight declines as the surface area to weight ratio decreases. This is seen in both broiler chickens and turkeys (see Table 7.2).
2. **Breed**, **variety**, **strain**, and **line**. The development of breeds and strains for specific purposes has resulted in genetic differences in the efficiency of energy utilization.
3. **Activity**. Birds that have access to large areas have a higher metabolic rate than their counterparts that have restrictions to their movement.
4. **Diurnal rhythm**. The metabolic rate is lower at night (period of darkness).
5. **Environmental temperature**. Poultry are sensitive to environmental temperature. With cold, there are increased energy expenditures to maintain body temperatures. Similarly with elevated environmen-

Table 7.2 Requirements of energy in poultry diets.

Poultry/Age	Energy Kcal—AMEn per kg Diet (MJ)*	Industry Recommendation kcal (MJ)**	Poultry/Age	Energy Kcal—AMEn per kg Diet (MJ)	Industry Recommendation kcal (MJ)
Broiler chickens					
0–3 weeks	3,200 (13.39)	—	0–10 days (starter)	—	3000 (12.55)
3–6 weeks	3,200 (13.39)	—	11–24 days (grower)	—	3100 (12.97)
6–8 weeks	3,200 (13.39)	—	24 days—market (finisher)	—	3200 (13.39)
Pullets (0–12 weeks)	2,850 (11.92)	—	Laying hens	2,900 (12.13)	—
Turkeys					
0–4 weeks	2,800 (11.71)	—	♂ 7–9 weeks; ♀ 7–8 weeks	—	3150 (13.18)
4–8 weeks	2,900 (12.13)	—	♂ 10–12 weeks; ♀ 9–10 weeks	—	3250 (13.60)
8–12 weeks	3,000 (12.55)	—	♂ 13–14 weeks; ♀ 11–12 weeks	—	3000 (12.55)
12–16 weeks	3,100 (12.97)	—	♂ 15–16 weeks; ♀13–14 weeks	—	3350 (14.01)
♂ and ♀ 0–4 weeks	—	3020 (12.63)	♂ 17–18 weeks; ♀15–16 weeks	—	3450 (14.43)
♂ and ♀ 5–6 weeks	—	3100 (12.97)	♂ 19–20 weeks; ♀ 17–20 weeks	—	3500 (14.64)
Growing ducks	3000 (12.55)	—			

*AMEn is nitrogen corrected apparent metabolizable energy.
**MJ megajoules
Based on NRC, 1994

tal temperatures, there are increased energy expenditures with panting to dissipate heat.

6. **Diet**. The metabolic rate of birds can be affected by diet itself.
7. **Level of production**. Rapid growth or high egg production increases energy requirements.
8. **Feather coverage**. Decreases in feathering causes some increase in energy requirement at low environmental temperatures.
9. **Other factors**. Disease and stress can also affect dietary requirements for energy.

7.4 Measuring and Expressing Energy Value of Feedstuffs

One nutrient cannot be considered more important than another because all nutrients must be present in adequate amounts if efficient production is to be maintained. Yet, historically, feedstuffs have been compared or evaluated primarily on their ability to supply energy to animals. This is understandable because energy is required in larger amounts than any other nutrient, energy may be the limiting factor in poultry production, and energy is the major cost associated with feeding poultry. Our understanding of energy metabolism has increased through the years. With this added knowledge, changes have come in both the methods and terms used to express the energy value of feeds.

Calorie System of Energy Evaluation

Calories are used to express the energy value of feedstuffs. To measure this heat, an instrument known as the bomb calorimeter is used, in which the feed (or other substance) tested is placed and burned in the

Textbox 7B

Energy Definitions and Conversions

Calorie (cal): A calorie is the amount of heat energy required to raise the temperature of 1 g of water by 1°C (precisely from 14.5° to 15.5°C). It is equivalent to 4.184 joules. Although not preferred, it is sometimes also called a "small calorie" and designated by being spelled with a lowercase c. This is a very small unit. In poultry and human nutrition, the common unit used is the kilocalorie.

Kilocalorie (kcal): The amount of heat energy required to raise the temperature of 1 kg of water 1°C (from 14.5° to 15.5°C). It is equivalent to 1,000 calories. In human nutrition, it is referred to as a kilogram calorie or as a large Calorie and is designated by being spelled with a capital C to distinguish it from the small calorie.

Megacalorie (Mcal): Equivalent to 1,000 kcal or 1,000,000 calories. While also referred to as a therm, this term is preferred.

British Thermal Unit (BTU): The amount of heat energy required to raise 1 lb of water 1°F; equivalent to 252 calories. This term is seldom used in animal nutrition.

Joule: An international unit (4.184 J = 1 calorie) for expressing mechanical, chemical, or electrical energy, as well as the concept of heat. In the future, energy requirements and feed values will likely be expressed by this unit.

presence of oxygen. The value determined in this analysis is termed **gross energy**.

Through various digestive and metabolic processes, numerous losses of the energy in feed occur as the feed passes through the bird's digestive system. These losses are illustrated in Figure 7.2. Measures that are used to express energy requirements and the energy content of feeds differ primarily in the digestive and metabolic losses that are included in their determination. The following terms are used to express the energy value of feeds:

- **Gross energy** (GE). Gross energy represents the total combustible energy in a feedstuff. It does not differ greatly between feeds, except for those high in fat.
- **Digestible energy** (DE). Digestible energy is that portion of the GE in a feed that is not excreted in the feces.
- **Metabolizable energy** (ME). Metabolizable energy represents that portion of the GE that is not lost in the feces, urine, and gas. Although ME more accurately describes the useful energy in the feed than does GE or DE, it does not take into account the energy lost as heat.
- **Net energy** (NE). Net energy represents the energy fraction in a feed that is available for maintenance and productive purposes. It is what is left after the fecal, urinary, gas, and heat losses are deducted from the GE. Net energy, because of its greater accuracy, is being used increasingly in diet formulations, especially in computerized formulations for large operations.

The poultry industry has found metabolizable energy (ME) to be the most reliable expression of energy needs and, in general, it represents 25 to 90% of gross energy. Other nutrient requirements are always considered in reference to the energy requirement. Using the energy level for reference will enable the nutritionist to form a ratio of the amount of the nutrient per unit of energy, thereby keeping the nutrients in balance with available energy. In eating to satisfy its energy need, a bird will eat less of a high-energy diet and more of a low-energy diet. Having the nutrients in relation to dietary energy will ensure proper intake on a daily basis.

Additional terms used to define the energy value of feeds are **true metabolizable energy** (TME) and **apparent metabolizable energy** (AME). True metabolizable energy is the gross energy of the feed minus the gross energy of the excreta of food origin. When a

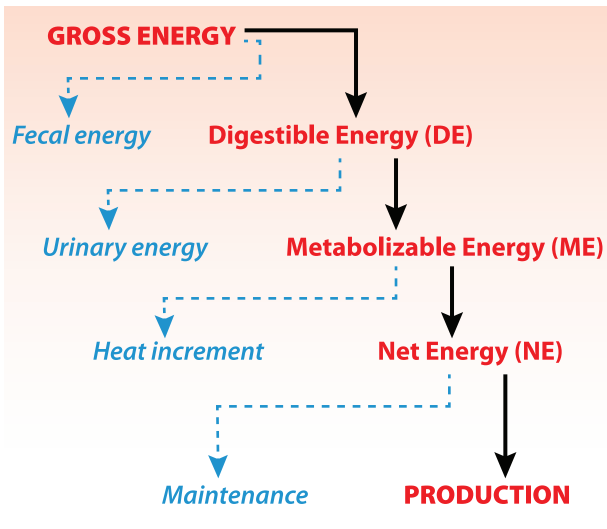


Figure 7.2 Components of energy utilization.

chicken is fasted there will still be losses of energy in the excreta (feces and urine). These energy losses are thus not from the feed but contain metabolic and endogenous fractions from the body. Correcting for these energy losses gives TME. Apparent metabolizable energy (AME) is often used for the traditionally determined energy values that include metabolic and endogenous fractions. In simple formulas, AME and TME are the following:

- AME = feed energy – (fecal + urinary + gaseous energy)
- TME = AME + (metabolic + endogenous energy)

In poultry, the gaseous losses are negligible and usually ignored. TME values are easier and much less expensive to determine than the traditional ME values. In growing animals, nitrogen is deposited in tissues primarily as protein. A correction is often made for the energy that would have been lost in association with nitrogen had it been excreted; the objective being to provide an energy measure that is independent of the growth of an animal and therefore more useful in formulating diets. So, ME and TME values when corrected for nitrogen excretion are expressed as ME_N and TME_N.

Following the nitrogen correction, the values obtained by use of TME assay are virtually identical to those obtained by using the more traditional apparent metabolizable energy; hence, nitrogen corrected TME (TME_N) and apparent metabolizable energy (AME) values are interchangeable.

7.5 Dietary Carbohydrates

It is first appropriate to include a few definitions:

- **Carbohydrates** are made of carbon, hydrogen, and oxygen (CHO) combined in set ways. Carbohydrates can be monosaccharides, disaccharides, and polysaccharides.
- **Monosaccharides** are simple sugars. Examples include glucose (for structure see Figure 7.3) and fructose. Monosaccharides are either pentoses (5 carbons)—e.g., arabinose, ribose, deoxyribose, and xylose—or hexoses (6 carbons)—e.g., galactose, glucose, fructose, and mannose.
- **Oligosaccharides** are composed of 2–10 monosaccharide units.
- **Disaccharides** are made up of two monosaccharides linked together. These can be digestible. Examples include **lactose** or milk sugar (made up of one glucose and one galactose), **sucrose** or sugar (composed of glucose and fructose), and **maltose** (made up of two glucoses).
- **Other oligosaccharides** are poorly digestible. Examples include **trisaccharides** (made up of three monosaccharides linked together)—e.g., raffinose, which is in soybeans—and **tetrasaccharides** (composed of four monosaccharides)—e.g., stachyose, which is also found in soybeans. There is apparent digestibility of some oligosaccharides (raffinose and stachyose) between the ileum of chickens and elimination of feces. This is due to microbial fermentation presumably in the ceca and the colon (large intestine).
- **Polysaccharides** are linear or branched polymers of monosaccharides. Examples of polysaccharides in plant-derived feed include **starch** (digestible; for structure see Figure 7.4) and **non-starch polysaccharide (NSP)**—fiber that are poorly digested by poultry. NSP includes **cellulose**, a non-digestible fiber, and **hemicellulose**, poorly digestible but fermentable (they can be broken down by bacteria in the ceca and colon) soluble fiber. Hemicellulose is a branched polysaccharide with a backbone consisting of xylose, mannose, and galactose and side chains containing arabinose, galactose, and 4-O-methyl-d-glucuronic acid.

Poultry do not produce the enzymes necessary to break down cellulose and hemicellulose. However, there is limited fermentation of hemicellulose (generating volatile fatty acids) in the ceca. The term often used for these compounds of limited digestibility is

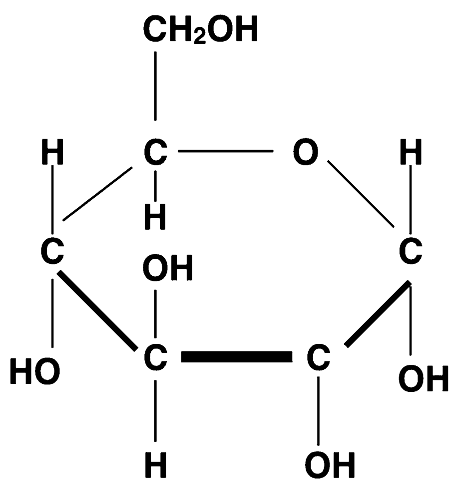
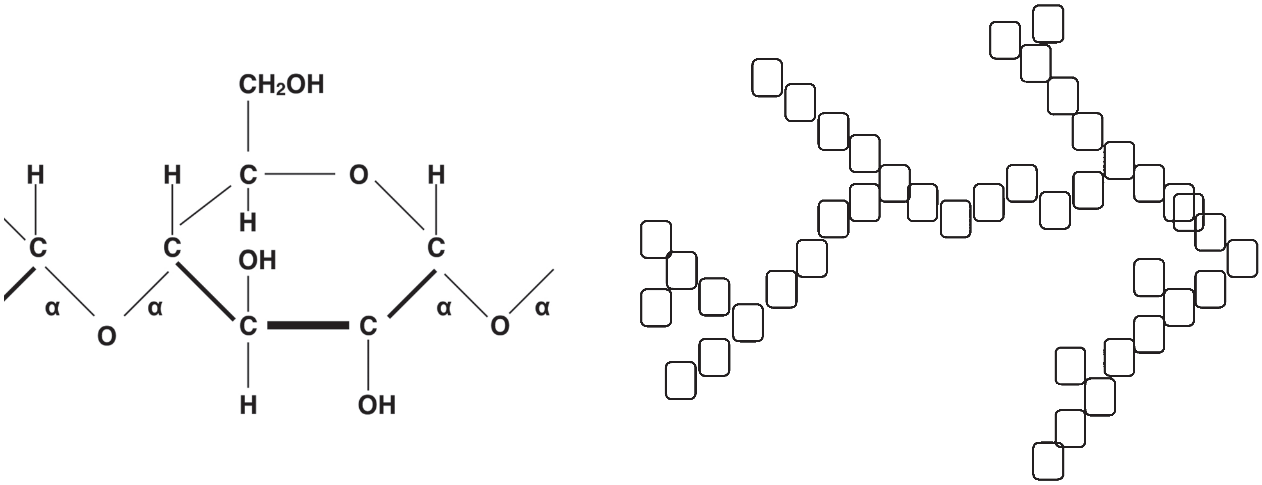


Figure 7.3 Chemical structure of glucose.



A. Glucose units linked together.

B. Conceptual diagram of the structure of glycogen showing glucose units linked together as a branched structure.

Figure 7.4 Chemical structure of starch.

"fiber." Fiber is largely insoluble and represents structural components of plants.

Carbohydrates are the major component of poultry feeds and are derived from cereals (e.g., corn) and legumes (e.g., soybeans). Glucose is the digestion product of the polysaccharide starch.

$$\text{Starch} \xrightarrow{\textit{Amylase}} \text{Maltose} \xrightarrow{\textit{Maltase}} \text{Glucose}$$

If digested, carbohydrates, predominantly glucose, are the primary source of energy in diets providing energy for all activities of poultry. In addition, glucose can be converted into triglyceride and stored in adipose tissue.

In poultry and other animals, carbohydrates are stored as glycogen, a polysaccharide that can be stored in the liver and muscles. The capacity to store glycogen is limited, however. When there is high availability of glucose, it is stored as the polymer glycogen; going up to 1% of muscle and 8% of the liver weights (see Figure 7.5).

The concentration of glucose in blood plasma is maintained between 200–250 mg% (mg per 100 ml or mg per dl) for chickens compared to 50–100 mg% for livestock. Between feeding, blood concentrations of glucose are replenished by breaking down the liver glycogen to generate glucose (along with glucose synthesized from amino acids and other metabolites) (see Figure 7.5). Glucose is the chief source of fuel for the energy needed for body processes in poultry.

7.6 Dietary Lipids (Fats)

There is no overall requirement of fat in poultry diets. Fats are a useful source of energy. Lipids (fats), like carbohydrates, contain three elements—carbon, hydrogen, and oxygen. Fats are soluble in organic solvents such as hexane, ether, chloroform, and benzene. Lipids in the feed are categorized as triglyceride, phospholipids, and cholesterol.

Triglyceride (TG, triacylglycerol, TAG, or triacylglyceride) is composed of three fatty acids and glycerol (see Figure 7.6). These are linked together by ester bonds. The major form of energy stored in adipose tissue (body fat stores) is triglyceride. As feeds, fats function much like carbohydrates in that they serve as a source of heat and energy and for the formation of fat. Because of the higher proportion of carbon and hydrogen, fats liberate more heat than carbohydrates when metabolized, furnishing approximately 2.25 times as much heat or energy per unit on oxidation as do the carbohydrates. A smaller quantity of fat is required, therefore, to serve the same function.

Although fats are used primarily to supply energy in poultry diets, they also improve the physical consis-

TEXTBOX 7C

A Deeper Dive: The Chemistry of Carbohydrates

What Are Carbohydrates?

Carbohydrates are made of carbon, hydrogen, and oxygen (CHO). The basic carbohydrate units are monosaccharides, or simple sugars. Glucose is the most common monosaccharide with a simplified formula of $C_6H_{12}O_6$ (see Figure 7.3). As it contains six carbon atoms, it is a hexose. Other hexoses include fructose, galactose, and mannose. Simple sugars can also have five carbon atoms. These are pentoses with a simplified structure of $C_5H_{9\text{ or }10}O_5$. Examples of pentoses are ribose (found in RNA), deoxyribose (found in DNA), arabinose, and xylose (found in wood and plant cell walls). Monosaccharides are most frequently found combined into large molecules called polysaccharides. In addition, there are some disaccharides.

Oligosaccharides in Poultry Feed

Oligosaccharides are found in poultry feed particularly reflecting their soybean meal contents:

- **Sucrose** is made up of glucose and fructose. Sucrose is found in soybeans at a concentration of 3–10 g per 100 g.
- **Raffinose** is composed of galactose, glucose, and fructose. Raffinose is found in soybeans at a concentration of about 1 g per 100 g.
- **Stachyose** is made up of two units of galactose and one unit each of glucose and fructose. Stachyose is found in soybeans at a concentration of 3–4 g per 100 g (Hymowitz and Collins, 1974; Choct et al., 2010; Kumar et al., 2010).

There is little marked digestion of raffinose and stachylose based on their quantification in the ileum but considerable fermentation presumed in the ceca and also possibly the colon based on the loss (> 80%) of raffinose and stachylose in the feces (Coon et al., 1990).

Polysaccharides

Polysaccharides differ with the sugar units (pentose and/or hexose), α- or β-glycosidic linkages and 1-3, 1-4, 1-5 and 1-6 linkages, and whether there is branching. Polysaccharides differ with the sugar units as follows:

- Pentosan—polysaccharide composed of pentose units.
- Hexosans—polysaccharide composed of hexose units.

Examples of polysaccharides include the following:

- Arabinans—polysaccharide composed of arabinose.
- Galactans—polysaccharide composed of galactose.
- Glucans—polysaccharide composed of glucose (α- or β-glycans).
- Mannan—polysaccharide composed of mannose.
- Xylans—polysaccharide composed of xylose.
- Glucomannans—polysaccharide composed of glucose and mannose.
- Galactomannans—polysaccharide composed of galactose and mannose.
- Xyloglucans—polysaccharide composed of xylose and glucose.

Importance of Starch

Starch is the major storage form of carbohydrate in plant seeds. Starch is a polymer (polysaccharide) composed of glucose units joined together by α-1,4-glycosidic bonds. Starch can be linear in amylose (with molecular weights of about 100,000 or 100 kDa) or branched in amylopectin (with molecular weights of about 105 kDa). Amylopectin consists of α-1,4-glucose chains with branches due to α-1,6-bonds. Starch is enzymically digested (broken down) to simple sugars by amylase.

What Are the Other Polysaccharides?

There are multiple non-starch polysaccharides including the structural carbohydrates in plants, namely cellulose and hemicellulose.

1. **Cellulose** is the most common macromolecule on the planet. It is however not digestible by poultry. Cellulose is composed of glucose units joined together by β-glycosidic (compared to α-glycosidic bonds in starch). The digestibility of cellulose is close to zero (e.g., Carré et al., 1990; Coon et al., 1990).
2. **Hemicelluloses** are β-1,4-polysaccharides (pentosans and hexosans) that are part of plant cell walls. The specific polysaccharides differ with the cereal or other common components of poultry feeds. These NPS include arabinans, galactans, glucans, mannans, xylans, arabinoxylan, glucomannans, galactomannans, and xyloglucans. Chickens have a limited capability to digest plant cell wall constituents such as water-soluble NSP (Carré et al., 1990). Their apparent digestibility based on fecal analysis is 9% for hemicellulose (Coon et al., 1990).

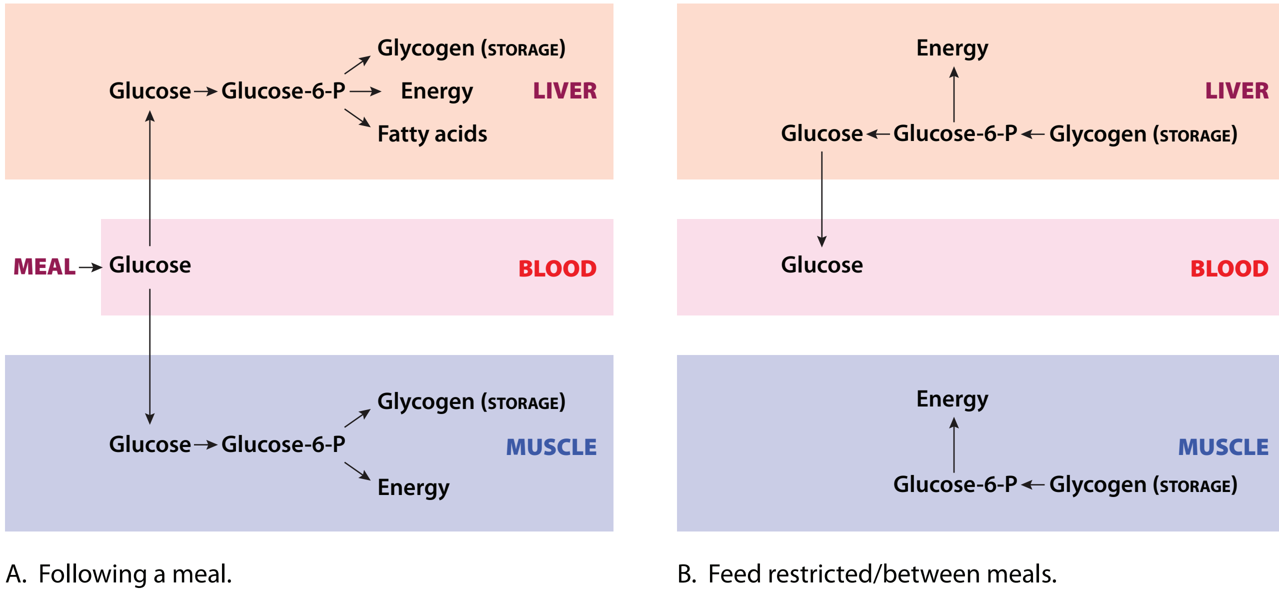


Figure 7.5 Summary of glucose metabolism including glucose conversion to glycogen.

tency of feeds and the dispersion of microingredients in feed mixtures, and serve as carriers for (and aid in the absorption of) fat-soluble vitamins. Fats used for feeding poultry are derived from three sources: (1) animal or poultry fats obtained from the rendering industry, (2) restaurant greases, and (3) acidulated soapstocks from the vegetable oil industry, and/or mixtures

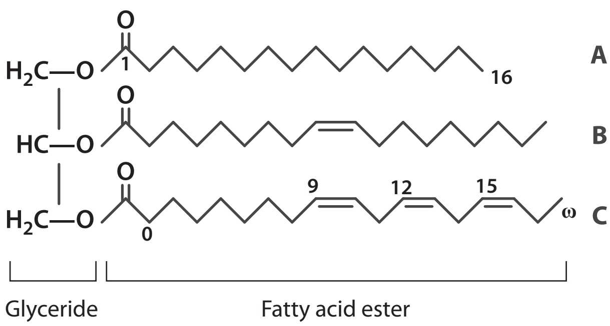


Figure 7.6 Structure of triglyceride. This is formed from glycerol bound to three fatty acids (as esters). Numbers indicate the length of the fatty acid. (A) shows an esterified saturated fatty acid (specifically palmitic acid). (B) shows an esterified monounsaturated fatty acid (specifically oleic acid). (C) shows an esterified polyunsaturated fatty acid (specifically α-linolenic acid). (Source: Modified from Wikimedia Commons)

thereof. The nutritional value of fats for poultry feed is determined by moisture, impurities, unsaponifiable lipids, free fatty acids, total fatty acids, and fatty acid composition. The following is the requirement for the essential fatty acid **linoleic acid**:

- Broiler chickens: 1% to 1.25%
- Growing turkeys: 0.8% to 1.25%
- Laying turkeys: 1.1%

Fats in the diet can aid the supply of fat-soluble vitamins.

The polyunsaturated linoleic and arachidonic acids are also considered to be essential fatty acids. They have specific functions in the body that are not related to energy production. Birds exhibit poor growth, fatty livers, reduced egg size, and poor hatchability without these essential fatty acids. Fats for poultry feed should be stabilized against oxidation. The metabolizable energy (ME) contribution of fats may be influenced by their fatty acid composition, free fatty acid content, level of fat inclusion in the ration, ingredient composition of the ration, and age of poultry. Fats often increase the utilization of dietary energy by poultry in excess of the increase expected when the ME of the fat is added to the ME values of the other ration constituents. Supplemental fats may increase energy utilization in adult chickens due to (1) a decreased rate of food passage through the gastrointestinal tract and (2) the heat increment of fat being less than that of carbohydrates.

TEXTBOX 7D

A Deeper Dive: Fatty Acids

Common fatty acids in the components of poultry diets are summarized in Textbox 7D Table 1.

N3 or ω-3 polyunsaturated fatty acids (PUFA) are so called as the first double is at carbon atom 3. Examples include α-linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid. **N6 or ω-6 PUFA** are so called as the first double is at carbon atom 6. Examples include linoleic acid and arachidonic acid.

Textbox 7D Table 1 Chemistry of common fatty acids.

Fatty Acid	Chemical Structure	C:D[1]	Type of PUFA
Saturated			
Lauric	CH3.(CH2)10.COOH	12:0	—
Myristic	CH3.(CH2)12.COOH	14:0	—
Palmitic	CH3.(CH2)14.COOH	16:0	—
Stearic	CH3.(CH2)16.COOH	18:0	—
Arachidic	CH3.(CH2)18.COOH	20:0	—
Monounsaturated			
Palmitoleic	CH3.(CH2)5.CH=CH.(CH2)7.COOH	16:1 (cis-Δ9)	n6 or ω-6
Oleic	CH3.(CH2)7.CH=CH.(CH2)7.COOH	18:1 (cis-Δ9)	n8 or ω-8
Polyunsaturated			
Linoleic	CH3.(CH2)4.CH=CH.CH2.CH= CH.(CH2)7.COOH	18:2 (cis, cis-Δ9, Δ12)	n6 or ω-6
α-Linolenic	CH3.CH2.CH=CH.CH2.CH= CH.CH2.CH=CH.(CH2)7.COOH	18:3 (cis, cis, cis-Δ9, Δ12, Δ15)	n3 or ω-3
Arachidonic	CH3.(CH2)4.CH=CH.CH2.CH= CH.CH2.CH=CH.CH2. CH=CH.(CH2)3.COOH	20:4 (cis, cis, cis, cis-Δ5, Δ8, Δ11, Δ14)	n6 or ω-6

[1] C is the number of carbon atoms; D is the number of double bonds 18:3.

Fats constitute about 17% of the dry weight of market broilers and about 40% of the dry weight of whole eggs. Food fats affect body fats, thus poultry consuming soft fat, such as vegetable oils, may accumulate fat that is more soft and oily than normal.

7.7 Dietary Protein and Amino Acid Requirements

Proteins are essential components of all living organisms. Crude protein refers to all the nitrogenous compounds in a feed. It is determined by finding the nitrogen content and multiplying the result by 6.25. The nitrogen content of protein averages about 16% (100/16 = 6.25).

Proteins are complex organic compounds made up of specific linear sequences of amino acids (for a portion of a peptide sequence see Figure 7.7). Proteins can have phosphate, carbohydrate, or lipid added to them, among other compounds. Amino acids always contain carbon, hydrogen, oxygen, and nitrogen but some also contain sulfur. There are 20 amino acids used to synthesize proteins. These can be categorized chemically as branched, carboxylic acids, amines, aromatic, and others (see Table 7.3). Examples of amino acids are summarized in Figure 7.8 and Table 7.4.

Amino acids (except glycine) can be in either L or D forms (or enantiomers or stereoisomers) (see Figure 7.9). This can be likened to "left" or "right" handed with each a mirror image of the other. All amino acids in proteins in poultry or other animals are in the L form. Amino acids are considered under three groups: (1) indispensable (essential), (2) conditionally indispensable, and (3) dispensable (formerly nonessential) (see Table 7.5).

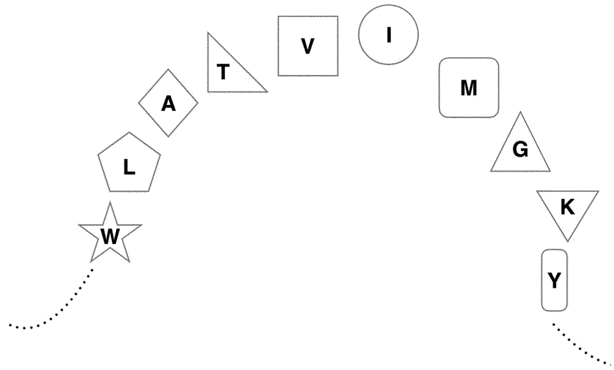


Figure 7.7 Structure of protein showing linear sequence of amino acids.

Indispensable amino acids must be obtained from the diet as the bird does not produce a sufficient amount. Dispensable amino acids can be obtained from the diet or made in the body. Conditionally indispensable can be made in the bird but not in sufficient quantities under specific circumstances. Indispensable amino acids can be converted to dispensable amino acids but not vice versa.

Indispensable amino acids $\rightarrow$ Dispensable amino acids

Dispensable amino acids $\nrightarrow$ Indispensable amino acids

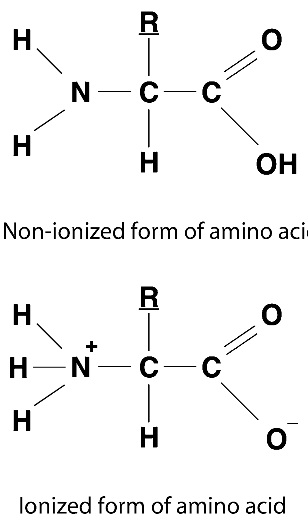


Figure 7.8 Chemical structure of generalized amino acids. (For R differences see Table 7.4.)

Table 7.3 Chemical groupings of amino acids.

Branched Chain Amino Acids
Leucine (L)
Isoleucine (I)
Valine (V)
Sulfur-containing
Methionine (M)
Cysteine (C)
Aromatic
Tryptophan (W)
Phenylalanine (F)
Tyrosine (Y)
Carboxylic acid
Aspartic acid (D)
Glutamic acid (E)
Amines
Asparagine (N)
Glutamine (Q)
Other
Glycine (G)
Proline (P)[1]

[1] Proline is hydroxylated in collagen (as hydroxyproline).

Plants have the ability to synthesize their own proteins from simple compounds in the soil and air including carbon dioxide, water, nitrate, and sulfates, using energy from the sun. Some plants such as legumes (including soybeans, common beans, and peas) have nitrogen-fixing bacteria in rhizobia in their roots. The nitrate is then used to produce proteins in the plant.

Table 7.4 Examples of amino acids.

Amino Acid	R Group
Glycine	-H
Alanine	$-CH_3$
Valine	$-CH-(CH_3)_2$
Leucine	$-CH_2-(CH)-(CH_3)_2$
Serine	$-CH_2-OH$
Lysine	$-(CH_2)_4-NH_2$
Cysteine	$-CH_2-SH$
Methionine	$-(CH_2)_2-S-CH_3$
Aspartic acid	$-CH_2-COOH$

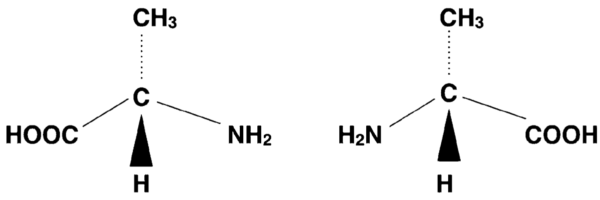


Figure 7.9 Structure of alanine to show the difference between L and D amino acids. (Hint: If you are confused, look at the positions of HOOC/COOH and NH_2/H_2N.)

Nitrogen Fixation

Converting nitrogen gas to compounds such as ammonium or nitrate ions. These latter can be used by plants.

Table 7.5 Classification of amino acids as indispensable, dispensable, or conditionally indispensable.

Indispensable (Essential) Amino Acids	Conditionally Indispensable (Essential) Amino Acids	Dispensable (Nonessential) Amino Acids
Arginine (R)	Cysteine (C)	Alanine (A)
Histidine (H)	Glycine (G)	Asparagine (N)
Isoleucine (I)	Tyrosine (Y)	Aspartic acid (D)
Leucine (L)		Glutamic acid (E)
Lysine (K)		Glutamine (Q)
Methionine (M)		Proline (P)
Phenylalanine (F)		Serine (S)
Threonine (T)		
Tryptophan (W)		
Valine (V)		

Proteins are widely distributed in animals. Proteins include enzymes, contractile proteins in muscles, and primary structural constituents of many tissues such as feathers, skin, ligaments, etc. Poultry require sufficient amounts of protein of suitable quality for (1) maintenance, (2) growth, and (3) reproduction/egg production. Protein requirements are summarized in Table 7.6 with those for growth being the greatest. Typical starter feed for broilers contains about 23% protein and typical laying feed about 15% protein (see Table 7.6). Protein requirements decline from starter to grower to finisher phases in broiler chickens. Initial protein requirements for growing turkeys are higher than those of broiler chickens but similarly decline during growth. Industry recommendations for today's broiler chickens and turkeys are either the same or higher than NRC recommendations.

From the standpoint of poultry nutrition, the amino acids that make up proteins are really the essential nutrients, rather than the protein itself. The ideal amino acids for growing poultry are considered in Textbox 7E. The requirements of the top three limiting amino acids—lysine, methionine (plus cysteine),

Textbox 7E

Some Ideal Amino Acid Requirements for Broiler Chicks and Laying Hens (Compared to Digestible Lysine).

	Broiler Chicks (NRC, 1994)	Broiler Chicks (Baker[1])	Hens (NRC, 1994)	Hens (CVB, 1996)	Hens (Mean 5 Studies*)
Lysine[2]	100	100	100	100	100
Methionine	46	36	43	50	48.2
Methionine and Cysteine	82	72	84	93	88.5
Threonine	73	67	68	66	74.4
Tryptophan	18	16	23	19	20.4
Arginine	114	105	105	—	103.7
Isoleucine	73	67	94	79	80.6
Valine	82	77	101	86	87.6

[1] Baker and Han, 1994.
[2] By definition.
* The five studies: Jais et al., 1995; Coon and Zhang, 1999; Bregendahl et al., 2008; Leeson and Summers, 2005; Rostagno, 2005.

Table 7.6 Requirements of protein and some essential amino acids as percentage of feed.[1]

	Poultry/Age	Protein	Lysine	Methionine and Cysteine	Threonine
NRC Requirements	**Broiler chickens**				
	0–3 weeks	23	1.1	0.90	0.80
	3–6 weeks	20	1.0	0.72	0.74
	6–8 weeks	18	0.85	0.60	0.68
	Laying hens	15	0.69	0.58	0.47
	Turkeys				
	0–4 weeks	28	1.6	1.05	1.0
	4–8 weeks	26	1.5	0.95	0.95
	8–12 weeks	22	1.3	0.8	0.8
	12–16 weeks	19	1.0	0.65	0.75
Industry Recommendations	**Broiler chickens**				
	Starter 0–10 days	23	1.44 (1.28)	1.08 (0.95)	0.97 (0.86)
	Grower 10–14 days	21.5	1.29 (1.15)	0.99 (0.87)	0.88 (0.77)
	Finisher 24 days–market	20	1.19 (1.06)	0.94 (0.83)	0.81 (0.71)
	Turkeys				
	♂ and ♀ 0–4 weeks	26–28	1.82 (1.73)	1.18 (1.12)	1.06 (1.01)
	♂ and ♀ 5–6 weeks	24–26	1.62 (1.53)	1.07 (1.01)	0.96 (0.90)
	♂ 7–9 weeks ♀ 7–8 weeks	23–25	1.47 (1.37)	0.99 (0.92)	0.88 (0.82)
	♂ 10–12 weeks ♀ 9–10 weeks	20–22	1.31 (1.21)	0.90 (0.82)	0.80 (0.73)
	♂ 13–14 weeks ♀ 11–12 weeks	18–20	1.17 (1.08)	0.82 (0.75)	0.73 (0.67)
	♂ 15–16 weeks ♀13–14 weeks	16–18	1.09 (0.99)	0.76 (0.69)	0.67 (0.61)
	♂ 17–18 weeks ♀15–16 weeks	15–17	1.01 (0.92)	0.75 (0.68)	0.62 (0.57)
	♂ 19–20 weeks ♀ 17–20 weeks	14–16	0.90 (0.82)	0.70 (0.64)	0.57 (0.52)

[1]( ) indicates digestible amino acid requirement. Based on NRC, 1994, and industry recommendations.

and threonine—are shown in Table 7.6. Grain usually supplies about one-half of the protein needs for most poultry feeds. Additional protein is supplied from high-protein concentrates. These can be of either vegetable (e.g., soybean meal) or animal origins. Protein concentrates can be supplemented by specific amino acids (e.g., lysine and methionine).

Poultry requires dietary sources of protein to furnish 13 different amino acids. These amino acids are referred to as essential since the chicken cannot produce them in sufficient amounts for maximum growth or egg production, and because a dietary deficiency of any one of them interferes with body protein formation and affects growth or egg production.

When formulating poultry feeds, they must be designed so as to supply all the essential amino acids in sufficient amounts. Special attention needs to be given to supplying the amino acids lysine, methionine, cystine, threonine, and tryptophan, which are sometimes referred to as the critical amino acids in poultry nutrition. Additionally, there must be sufficient total nitrogen for the chicken to synthesize the other amino acids needed. The amino acid requirements of growing chickens, turkeys, and laying hens are met by proteins from plant and animal sources together with added lysine, methionine, and other amino acids. Protein supplements that supply all the essential amino acids of the bird are known as high quality supplements. It may be necessary to use more than one source of dietary protein, combining them so that the amino acid composition of the mixture meets the requirements of the bird. More likely, specific limiting amino acids are added to meet the needs of the bird.

Excess protein consumed by the bird can be burned in the body to yield energy. However, in the feeding of poultry it is seldom wise to use excessive protein because carbohydrates and fats are generally more economical sources of energy. In addition to dietary energy concentration and ambient temperature, the following factors affect the amino acid requirements:

1. **The rate of growth or intensity of egg production**. The more rapid the growth and the higher the egg production, the higher the amino acid requirements.
2. **The strain /genetics**. Even within birds of like body size, growth rate, or egg production, there may be differences in requirements among strains.
3. The amino acid relationships, specifically:
   a. *Methionine-cysteine.* The requirement for methionine can be met only by methionine, while the requirement for cysteine may be met by cysteine or methionine. This is because methionine is readily converted to cysteine metabolically, while the reverse is not possible.
   b. *Phenylalanine-tyrosine.* The requirement for phenylalanine may be met only by phenylalanine, while the requirement for tyrosine may be met by tyrosine or phenylalanine.
   c. *Glycine-serine.* Glycine and serine can be used interchangeably in poultry diets.
4. **Antagonisms**. There are specific antagonisms among amino acids that may be structurally related (e.g., valine-leucine-isoleucine and arginine-lysine). Increasing one or two of such a group may raise the need for another of the same group.
5. **Imbalances**. In supplementing diets with limited amino acids (lysine and methionine), it is important to supplement first with the most limiting one, followed by the second-most limiting one, etc. Over-supplementation with only the second- or third-most limiting one may create an imbalance and accentuate the primary deficiency.
6. **Amino acid availability or digestibility**. The usual assumption that amino acids are 80 to 90% available is not necessarily valid. For example, feathers or blood are either indigestible in native form or become indigestible by overheating in processing.

The consequences of a protein or amino acid deficiency vary with the degree of the deficiency. A borderline deficiency is characterized by poor growth and feathering, reduced egg size, poor egg production (but hatchability is not affected), tendency toward greater deposition of carcass and liver fat, poor feed conversion into eggs or meat, and lack of melanin pigment in black or reddish feathers with low lysine. A severe protein deficiency is marked by stopping feed intake; stopping egg production; loss of body weight; resorption of ova; a tongue deformity with leucine, isoleucine, and phenylalanine deficiency; stasis of the digestive tract; and death.

True Digestibility of Amino Acids

It is important to determine amino acid availability using some of the same techniques that were originally developed for determination of true metabolizable energy. This stems from amino acids being not completely utilized due to characteristics of the feedstuff. It is possible to differentiate between apparent and true digestibility. In addition to nonabsorbed amino acids, the excreta also contain materials originating in the tissue of the bird (e.g., microorganisms, cells sloughed from the gut wall, mucus, bile, unabsorbed digestive juices, etc.). Apparent digestibility makes no correction for these endogenous components.

The availability of amino acids in feedstuffs is estimated by three main methods: (1) in vitro tests, (2) growth tests, and (3) digestibility tests. Digestibility trials can measure the digestibility of all amino acids in a feedstuff in one study. Various experimental techniques may be applied to determine the digestibility of amino acids. The rooster precision-feeding technique estimates the true digestibility of amino acids. It consists of force-feeding a precise quantity of feed to an adult rooster fasted for, say, 24 hours followed by a 48-hour collection period of the excreta. Other birds are fasted throughout the experiment to allow for collection of the endogenous excreta. It appears that true amino acid digestibility established in the chicken is valid for other poultry species. Alternatively, the apparent digestibility can be measured by determining the contents of ingesta in the ileum and comparing to a nonabsorbed marker such as chromium oxide. Diet formulation on the basis of digestible amino acids has the following advantages:

1. It improves performance prediction under practical conditions.
2. It allows more by-product and alternate protein sources to be included in poultry feeds, along with the possibility of reducing costs while minimizing the risks of deterioration in performance.

3. It reduces the variability of poultry performance.
4. It evaluates feedstuff and rations more precisely.
5. It makes possible a more accurate supply of amino acids required for optimal performance.

The disadvantages or reservations relative (1) to the rooster bioassay technique for determining the true digestibility of amino acids in feedstuffs, and (2) to the use of such values in feed formulations are:

1. It does not consider the effects of ceca and other microbial populations on dietary protein. Microbes both utilize and synthesize amino acids. Some can be utilized by the bird. Moreover, about 20% of the amino acids in the excreta are of microbial origin. This can be addressed using cecectomized roosters.
2. When conventional feed ingredients are used in poultry feeds, consideration of amino acid digestibility is not particularly advantageous as they are relatively consistent.

Crystalline amino acids, not being protein bound or enclosed in a feedstuff impairing their digestion, are effectively 100% digestible and 100% available.

7.8 Mineral Requirements

Minerals are elements, frequently found as salts with either inorganic elements or organic compounds. Minerals are essential to all body functions and are considered as either macrominerals (required in relatively large amounts) or trace elements (required in trace amounts), specifically cobalt (Co) (in vitamin B_{12} and considered under vitamins below), copper (Cu), chromium (Cr), iodine (I), iron (Fe as ferrous iron), manganese (Mn), selenium (Se), and zinc (Zn).

Major or Macrominerals

The major or macrominerals of importance in poultry are calcium (Ca), sodium (Na), chloride (Cl), potassium (K), phosphorus (P) (as phosphate as PO_4), magnesium (Mg), and sulfur (S), predominantly in methionine and cysteine and as such was considered under amino acids (above). The roles of macrominerals in poultry are summarized in Table 7.7 with requirements shown in Table 7.8.

Sodium (Na), Potassium (K), and Chloride (Cl)

Sodium, potassium, and chlorine are essential in the diets of poultry and other animals. Diets provide sodium, potassium, and chlorine. These have important roles including osmotic balance, blood pressure, acid-base balance, nerve conduction, and muscle contraction. The NRC requirements for sodium, chloride,

Table 7.7 Role of macrominerals in poultry.

Mineral	Roles
Calcium (Ca)	Bone (calcium phosphate as hydroxyapatite [$Ca_{10}(PO_4)_6(OH)_2$]) + cell signaling + muscle contraction + blood clotting+ major constituent of egg shells.
Sodium (Na)	Maintaining osmotic balance, major cation in blood plasma and blood pressure + nerve conduction.
Chloride (Cl)	Maintaining osmotic balance, major anion in blood plasma and blood pressure + major constituent of egg shells.
Magnesium (Mg)	Cell functioning (co-factor for multiple enzymic reactions) + present in bone + muscle growth + nerve and immune functioning.
Phosphorus (P) (as phosphate)	Bone (calcium phosphate) + critical components of cells (DNA, RNA, ATP and phosphoproteins) + acid-base balance.
Potassium (K)	Maintaining osmotic balance, major cation in cells + nerve conduction.

Table 7.8 Macromineral requirements of poultry expressed as g per kg feed.

	Growing Broiler Chickens	Growing Turkeys	Growing Ducks	Laying Hens
Calcium (Ca)	9	8.5	6	32.5
Sodium (Na)	1.5	1.2	1.5	1.5
Chloride (Cl)	1.5	1.2	1.2	1.3
Magnesium (Mg)	0.6	0.5	0.5	0.5
Phosphorus (P) (available)	3.5	3.8	3	2.5
Potassium (K)	3.0	5	—	1.5

Based on NRC, 1994.

and potassium are shown in Table 7.8. Industry recommendations are that feed should contain 0.32 to 0.46% salt (sodium chloride) and potassium should represent 0.4 to 0.9% of the diet for growing broiler chickens. Plant feedstuffs normally provide sufficient potassium. If there is insufficient sodium, potassium, and chlorine in the diet, the following are depressed: growth, bone development, egg production, eggshell quality, and amino acid utilization. Deficiencies cause the following specific issues:

- Chloride—lack of controlled movement and nervousness.
- Potassium—hypokalemia, muscle weakness, intestinal distention, and problems with both heart and respiratory functioning.
- Sodium—hyponatremia and associated reductions in blood osmotic pressure, cardiac output, and impairments in acid-base control.

Definitions

Hypokalemia or low concentrations of potassium in the blood. Hypokalemia can be caused by insufficient potassium in the diet.

Hyponatremia or low concentrations of sodium in the blood. Hyponatremia can be caused by insufficient sodium in the diet.

Electrolyte balance is approximated as the following: $Na^+ + K^+ - Cl^-$.

Calcium (Ca) and Phosphorus/Phosphate (P)

Calcium and phosphate are important nutrients as they are major components of bone. In addition, calcium is important in muscle contraction, blood clotting, some intracellular enzymes, and cell signaling, along with shell formation in hens. Phosphate plays an important role as a component of phospholipids (e.g., in cell membranes and lung surfactant), phosphoproteins, DNA, RNA, and ATP. Deficiencies of calcium reduce growth, egg production, and bone mineralization, together with causing soft-shelled eggs. The availability of calcium is high for most commonly used supplements, but the biological availability of phosphorus in supplements varies, being low from phytate phosphate from plants (about 30%; discussed in more detail in Chapter 8).

The calcium requirements of poultry are shown in Table 7.9. The needs of the laying hen are high due to egg production. Deficiencies in calcium and/or phosphorus will be followed by weakness of bones and leg problems. Calcium deficiency in laying hens is followed by thinning of the eggshells, ultimately to shell-less eggs and then egg production stopping altogether. It is also essential (especially in poultry housed in confinement) that adequate amounts of vitamin D_3 be supplied in the ration to ensure proper absorption of these elements.

Table 7.9 Calcium requirement of breeding poultry (g per kg feed).

Species	Calcium Requirement (g per kg Feed)
Laying hens (white eggs) (at 0.1 kg feed per day)	33
Laying hens (brown eggs) (at 0.1 kg feed per day)	40
Laying turkeys	22.5
Ducks	27.5

Based on NRC, 1994.

Magnesium (Mg)

Magnesium is required for multiple cellular roles (Table 7.7). Dietary magnesium levels of between 0.05% and 0.5% are recommended for broilers. Plant feedstuffs in poultry diets normally provide sufficient magnesium. Excessive magnesium levels can interfere with the absorption of other elements—notably calcium and phosphorus. If it is known that a diet contains a high level of magnesium, levels of other elements should be increased. Magnesium deficiency is associated with slow growth, lethargy, panting, gasping, and mortality.

Trace or Microminerals

Trace minerals are minerals that are required in small amounts. The roles of microminerals in poultry are summarized in Table 7.10. The trace minerals of special concern in poultry are copper (Cu), chromium (Cr), iron (Fe), iodine (I), manganese (Mn), selenium (Se), and zinc (Se). The NRC requirements for trace elements in poultry are summarized in Table 7.11. Industry recommendations for the amounts of copper, iodine, manganese, selenium, and zinc to be added to broiler chicken feeds are higher than the NRC overall requirements. There are interactions between various trace and other minerals or nutrients such as copper and molybdenum, selenium and mercury, calcium and zinc, calcium and manganese, and selenium and vitamin E.

Copper (Cu)

Copper is important in metabolism with copper-containing enzymes (cuproenzymes) critical to oxidation-reduction (cytochrome *c* oxidase), to linking collagen to elastin in connective tissue, and in iron metabolism in poultry. Copper requirements are shown in Table 7.11. Deficiencies of copper are associated with anemia, fragile bones, lameness, and, in turkeys, aortic rupture.

Iodine (I)

Iodine is essential for the production of the thyroid hormone thyroxine. This is required for normal metabolism, nervous system development, growth, and reproduction. The NRC requirements for iodine are 300 ppb (μg per kg) for laying hens and 350 ppb for young chicks. However, industry recommendations are higher (Table 7.11). Iodine deficiency is associated with reduced growth and egg production together with obesity (large increase in fat deposition).

Table 7.10 Role of trace minerals in poultry

Mineral	Role
Cobalt	Critical component of vitamin B_{12}
Copper (Cu)	Co-factor for enzyme reactions + important to iron metabolism
Chromium (Cr)	Control of glucose metabolism
Iodine (I)	Essential for the production of thyroxine (thyroid hormone) and hence to the control of metabolism and to growth
Iron (Fe)	Essential for synthesis of hemoglobin and hence transport of oxygen + component of myoglobin
Manganese (Mn)	Co-factor for enzyme reactions
Selenium (Se)	Antioxidant
Zinc (Zn)	Co-factor for enzyme reactions + production of sperm + immune functioning + growth

Iron (Fe)

Iron is essential for the biosynthesis of hemoglobin (and hence transport of oxygen) and myoglobin (Table 7.10). It is also a critical part of cytochromes (essential for producing usable energy in cells) and is important to DNA synthesis and peroxidases. The NRC requirements for iron are 60 mg per kg feed for young chicks. However, industry recommendations for additions to poultry diets are lower (Table 7.11). Deficiency of iron can be due to insufficiency in the diet or some toxic compounds such as the fungal toxin ochratoxin. Iron deficiency causes anemia (lack of hemoglobin and erythrocytes).

Manganese (Mn)

Manganese is a co-factor for enzymes including manganese superoxide dismutase, protecting the integrity of mitochondria from oxidants; pyruvate carboxylase and phosphoenolpyruvate carboxykinase (PEPCK), enzymes in the glucogenesis (synthesis of glucose from glycogenic amino acids) pathway; arginase, a liver enzyme in urea cycle; and glutamine synthetase—glutamate to glutamine. Required dietary levels of manganese are shown in Table 7.11 with industry recommendations higher. Chicks that are deficient in manganese characteristically display slipped tendons (perosis) and show a "star-gazing" posture

Table 7.11 Trace mineral requirements of poultry expressed as mg per kg feed.

Mineral	NRC Requirement for Growing Broiler Chickens	Industry Recommended Addition to Diet (Final Concentration) for Growing Broiler Chickens	NRC Requirement for Growing Turkeys	NRC Requirement for Growing Ducks[1]
Copper (Cu)	8	16	6	
Iodine (I)	0.35	1.25	0.4	
Iron (Fe)	80	20	60	
Manganese (Mn)	60	120	60	50
Selenium (Se)	0.15	0.3	0.2	0.2
Zinc (Zn)	40	110	40	60

[1] In the absence for specific requirements in ducks, the values for broiler chickens are assumed.

Based on NRC, 1994, and Ross 308s.

due to problems with the inner ear. Hens with manganese deficiency have reduced egg production, egg shell thickness, and hatchability. Embryos from manganese-deficient hens show abnormalities including chondrodystrophy (short legs and wings), edema, and so-called "parrot beak."

Selenium (Se)

Generally, selenium is viewed as having an antioxidant role (Table 7.10). Specifically, selenium is part of the amino acid selenocysteine. This amino acid is found in glutathione peroxidases, thioredoxin reductases, iodothyronine deiodinases, and methionine sulfoxide reductase B1. The selenium containing glutathione peroxidases protect against oxidant damage. Chicks deficient in selenium show ruffled feathers and unthriftiness. They develop edema (fluid in the tissue), exudative diathesis, pancreatic fibrosis, and frequent bruising. Selenium-deficient turkeys develop a condition commonly referred to as "white gizzard disease," a form of muscular dystrophy. Selenium-deficient hens have reduced egg production and hatchability. Care should be taken in the incorporation of selenium in poultry feeds since it is toxic at high levels.

Zinc (Zn)

Zinc is an essential co-factor for over 300 enzymes. In addition, zinc is important to cell membranes, to the structure of some proteins, to immune functioning, and to growth/development. Required levels of zinc are shown in Table 7.11 with industry recommendations higher. Zinc deficiency reduces growth in young chicks and egg production in laying hens. Zinc deficiency in chicks can result from an insufficient diet or to zinc being unavailable due, for instance, to being chelated (tightly bound) by phytate phosphate. Zinc deficiency causes the following problems in chicks: slower growth, shorter leg bones, enlarged hock joints, feet skin becoming scaly, poor feathering, loss of appetite, and even death. Chicks hatched from zinc-deficient eggs show extremely poor health, having labored breathing and being unable to walk, eat, or stand.

7.9. Vitamin Requirements

What Is a Vitamin?

Vitamins are defined as complex organic compounds that are required in minute amounts by an animal species for normal growth, production, reproduction, and/or health. Vitamin C is synthesized by poultry and hence, it is not considered a required dietary nutrient. There is some evidence, nevertheless, of a favorable response to vitamin C by birds under stress.

Table 7.12 The role of vitamins in poultry.

Vitamin	Roles
Water soluble	
Vitamin B_{12}	Red blood cell production + nervous functioning + DNA and RNA metabolism.
Biotin	Co-enzyme in cell functioning.
Choline	Synthesis of acetyl choline (neurotransmitter) + phospholipids + lipid transport + allows methyl group transfer in cells.
Folacin	Co-enzyme in cell functioning + red blood cell production + nervous functioning.
Niacin	Co-enzyme in cell functioning + nervous functioning.
Pantothenic acid	Co-enzyme (part of coenzyme A) in cell functioning.
Pyridoxine	Co-enzyme in cell functioning + synthesis of neurotransmitters (serotonin, melatonin, and norepinephrine).
Riboflavin	Co-enzyme in cell functioning.
Thiamin	Co-enzyme in cell functioning.
Fat soluble	
Vitamin A	Development of skin, bone, and other tissues + eye functioning
Vitamin D	Precursor for the formation of calcium controlling hormone - 1,25 dihydroxyvitamin D or calcitriol.
Vitamin E	Antioxidant.
Vitamin K	Blood clotting by clotting factor, prothrombin.

Role, Requirements, and Deficiencies in Vitamins

The vitamins required by poultry and their roles are summarized in Table 7.12. When poultry are on diets deficient in vitamins they exhibit specific symptoms (summarized in Table 7.13). To ensure that vitamin requirements are met, the diets of poultry should be supplemented with vitamins or a vitamin mix. Table 7.14 summarizes the NRC requirements for satisfactory vitamin levels in poultry feed together with industry recommendations for vitamin additions to broiler feed. In-

Table 7.13 Deficiencies of vitamins in poultry ↑↓.

Vitamin	Disorder	Deficiency Symptoms
Water soluble		
Vitamin B_{12}	Pernicious anemia	Growth ↓, mortality ↑, perosis (chondrodystrophy), hatchability of eggs ↓.
Biotin	Biotin deficiency	Dermatitis (feet, face). Chicks: anorexia (feed intake ↓), perosis, coordination ↓, poor feathering, fatty liver and kidney syndrome. Adults: blue comb and paralysis.
Choline	Choline deficiency	Chicks: Growth ↓ & perosis (in hock joint). Adults: mortality ↑, egg production ↓.
Folacin	Folate deficiency	Anemia (macrocytic or megaloblastic due to DNA synthesis ↓), leukopenia (leukocyte numbers ↓), whitening of comb. Chicks: growth ↓, appear anemic, poor feathering, mortality ↑. Adults: hatchability. Embryos: mortality ↑, beaks deformed, tibiotarsus bent.
Niacin	Pellagra or niacin/ nicotinic acid deficiency	Appetite ↓, weakness ↑, diarrhea. Chicks: Growth ↓, tibiotarsal joint enlarged, bowing of legs, oral cavity, and esophagus inflamed with "black tongue", poor feathering. Symptoms ↑ in young turkeys, ducks, geese, and pheasants.
Pantothenic acid	Pantothenic acid deficiency	Chicks: growth ↓, poor feathering, dermatitis (feet), liver weight ↓. Adults: egg production ↓, hatchability ↓. Embryos: from hens subcutaneous hemorrhages and edema.
Pyridoxine	Pyridoxine deficiency	Chicks: growth ↓, dermatitis, and anemia. Adults: appetite ↓, egg production ↓.
Riboflavin	Riboflavin deficiency	Chicks: "curled-toe" paralysis, growth ↓, reluctance to move with leg muscle ↓, skin is dry, and embryos size ↓.
Thiamin	Beriberi or thiamin deficiency	Chicks: lethargy and head tremors, "star gazing" look with retraction of head due to paralysis of neck muscles, topple over, appetite ↓.
Fat soluble		
Vitamin A	Vitamin A deficiency or hypovitaminosis A	Weakness and ruffled feathers. Chicks: Growth ↓, anorexia, drowsiness, coordination ↓, emaciation. Adults: hatchability ↓, egg production ↓, mucous glands functioning ↓ leading to infection and discharge from eyes and nose.
Vitamin D	Vitamin D deficiency	Chicks: rickets (abnormal bone growth), growth ↓, poor feathering. Adults: bone strength ↓, hatchability ↓, egg shell production ↓.
Vitamin E	Vitamin E deficiency	Chicks: encephalomalacia (atrophy of brain), exudative diathesis (subcutaneous edema), and staggering and lack of balance (muscular dystrophy).
Vitamin K	Vitamin K deficiency	Impaired blood coagulation (clotting time ↑) leading to hemorrhaging.

dustry guides recommend that the levels of vitamins E, D, A, C, and niacin should be increased. In addition, betaine should be added for broiler chickens raised at elevated temperatures.

Fat-Soluble Vitamins

Vitamin A

Vitamin A is a series of retinoids including retinol, retinal, and retinal esters. Vitamin A can be formed from carotenoids such as β-carotene. Roles of vitamin A include vision, with retinal being part of the visual pigment rhodopsin in the retina of the eyes; embryonic development; immune functioning; and reproduction (see Table 7.12). The amount of vitamin A needed in poultry feed depends on multiple factors independent of species and genetics, losses during feed storage, and the amount of vitamin A from the yolk stored in the liver of the newly hatched chick. The NRC requirements and industry recommendations are summarized in Table 7.14.

Young chicks are more susceptible to vitamin A deficiencies than adults because it takes a relatively long period for adult birds to deplete their stores of vitamin A. Deficiency symptoms of vitamin A in chicks are characterized by disrupted mucosal membranes with small white pustules, retarded rates of growth, emaciation, general weakness, staggered gait, ruffled plumage, lowered resistance to infection, and xerophthalmia (white solid accumulating in the eyes). In adults, eye problems are prevalent along with de-

Table 7.14 Vitamin requirements for poultry expressed as either mg or IU per kg feed.

Vitamin	NRC Requirement for Growing Broiler Chickens	Industry Recommended Addition to Corn-Based Diet (Final Concentration) for Growing Broiler Chickens	NRC Requirement for Growing Turkeys	NRC Requirement for Growing Ducks[1]
Water soluble (mg)				
Vitamin B_{12}	0.01	0.017	0.003	—
Biotin	0.15	0.22	0.125	—
Choline	1000	1700	1100	—
Folacin	0.55	2.2	0.8	—
Niacin	30	65	50	55
Pantothenic acid	10	20	9	11
Pyridoxine	3.5	4.3	3.5	2.5
Riboflavin	3.6	8.6	3	4
Thiamin	1.8	3.2	2	—
Fat soluble				
Vitamin A (IU)	1500	12,000	5000	2,500
Vitamin D (IU)	200	5000	1100	400
Vitamin E (IU)	10	80	10	—
Vitamin K (mg)	0.5	3.2	0.75	0.5

[1] In the absence for specific requirements in ducks, the values for broiler chickens are assumed.

Based on NRC, 1994.

creased egg production and hatchability. Excessive amounts of vitamin A can be toxic but these levels must be on the order of 500 times the recommended allowances. Symptoms of excess vitamin A (hypervitaminosis) are anorexia, emaciation, inflammation of epithelial tissues, abnormalities of bone, swelling of the eyelids, and mortality.

Vitamin D

Cholecalciferol (D_3) is the form of vitamin D that has the highest activity in poultry feed. Today, most birds are reared in confinement where exposure to sunlight is insufficient for the conversion of 7-dehydrocholesterol (the precursor of vitamin D in the skin) to vitamin D_3. Vitamin D_3 is routinely added to poultry feed (for requirements see Table 7.14). Vitamin D_3 is activated to a hormone, 1,25 dihydoxycholecalciferol [1,25 $(OH)_2D_3$) or calcitriol], in the liver and kidney. It has a critical role in the control of calcium; increasing intestinal calcium absorption and assuring bone development (also see Table 7.12).

Symptoms of vitamin D deficiencies in growing chicks and other poultry include leg problems (rickets with bowed legs), depressed growth, and poor feathering (also see Table 7.13). In vitamin D-deficient adults there are the following issues: decreased egg production and eggshell quality, reduced hatchability, and bone weakness with increased risk of breakage.

Vitamin E

There are at least eight chemical forms of vitamin E (α-, β-, γ-, δ-tocopherol, and α-, β-, γ-, δ-tocotrienol). Vitamin E has an important role as an antioxidant, preventing adverse effects of free radicals in cells (such as reactive oxygen species; see Table 7.12). NRC requirements and industry recommendations for vitamin E are given in Table 7.14. The symptoms of vitamin E deficiency in chicks are (1) encephalomalacia ("crazy chick disease" with lesions in the brain), (2) exudative diathesis (walls of capillaries becoming highly permeable), and (3) muscular dystrophy (with degeneration of breast and, to a less extent, muscle fibers). Chicks with vitamin E deficiency exhibit an outstretching of the legs with toes curled; and the head is often in a retracted position. Prior to these symptoms of acute toxicity, chicks display a generalized lack of coordination.

Reproduction is impaired in vitamin E-deficient adult birds. Degeneration of the testes is observed in deficient males—a condition that can lead to permanent sterility if not corrected in time. Layers suffering from vitamin E deficiency do not show a dramatic drop in egg production but hatchability is severely reduced. In vitamin E-deficient turkey poults, a myopathy of the gizzard can be observed. Selenium and vitamin E are closely related in physiological functions but they cannot replace each other in the diet.

Vitamin K

Vitamin K consists of a number of compounds. There are two major natural forms, these being, respectively:

- Phylloquinone (vitamin K_1).
- A series of forms of minaquinone (vitamin K_2)—MK-4 through MK-13.

In addition, there is menadione (vitamin K_3), synthetic vitamin K, that can be used as the reference standard for vitamin K activity. Vitamin K is important for the production and action of the clotting factor prothrombin (see Table 7.12). This action is opposed by Coumadin® (warfarin), a vitamin K antagonist. Vitamin K is also the coenzyme for vitamin K-dependent carboxylase and is important for the actions of Matrix Gla-protein, a bone and cartilage protein.

Vitamin K should be added to poultry feeds (for required and recommended levels see Table 7.14). When heavy parasitic infections occur, such as in coccidiosis, the vitamin K requirement is increased. Vitamin K-deficient poultry are anemic and have a greatly increased susceptibility to hemorrhaging and an increased blood clotting time (see Table 7.13). The level of prothrombin in the blood is greatly reduced in vitamin K-deficient chicks.

Water-Soluble Vitamins

While the ingredients of poultry diets contain water-soluble vitamins, they need to be added to the feed.

Biotin

Biotin is a B vitamin (B_7) that is added to poultry feed (for required and recommended levels see Table 7.14). Biotin is important as a coenzyme for specific enzymes, such as carboxylases (enzymes adding or removing carbon dioxide), enzymes in fatty acids synthesis, enzymes critical to isoleucine, and valine metabolism and enzymes in the process of gluconeogenesis (production of glucose from amino acids or lactate). The symptoms of biotin deficiency in chicks are cracking and degeneration of skin on the feet and around the beak, and perosis. Reduced hatchability is observed in biotin-deficient hens (see Table 7.13).

Choline

Choline is added to poultry feeds (for required and recommended levels see Table 7.14). Choline is a critical component to one phospholipid, phosphatidyl choline (see Table 7.12). Phosphatidyl choline forms part of cell membranes. Much like the deficiency symptoms of several of the other water-soluble vitamins, growth depression and perosis (slipped tendon) can be observed in choline-deficient chicks (see Table 7.13).

Choline and Eggs

Eggs (see Figure 7.10) are an excellent source of choline, containing the following:

- Choline—250 mg per 100 g.
- Choline as phosphatidylcholine—240 mg per 100 g.
- Total phospholipid 0.73 g per 100 g; the vast majority being phosphatidylcholine.

The high choline content of eggs is to meet the needs of the developing embryo. Phosphatidylcholine is important for the structural integrity of the cell membranes and as lung surfactant.

Folic Acid

Folic acid is also called folate, folacin, pteroylglutamic acid, and vitamin B_9. It is necessary to supplement poultry feeds with folic acid (for required and recommended levels see Table 7.14). Folate is a coenzyme in reactions that are part of the metabolism of amino acids such as glycine, serine, cysteine, and methionine (also see Table 7.12). Deficiency symptoms of fo-

Figure 7.10 Eggs are excellent sources of choline found in phospholipids. (Source: Mr.Nakorn/ Shutterstock)

lacin in chicks are poor growth, abnormal coloration of feathers, perosis, and anemia. Hens that are deficient in folacin are observed to have reduced egg production and hatchability. Poults fed rations deficient in folic acid may develop a paralysis of the neck (see Table 7.13).

Niacin

Niacin is added to poultry feed (for required and recommended levels see Table 7.14). Some niacin can be synthesized in the body from tryptophan but this is insufficient to meet the needs of poultry. Niacin is converted to the coenzymes nicotinamide adenine dinucleotide (NAD) and nicotinamide adenine dinucleotide phosphate (NADP) (see Table 7.12). Chicks deficient in niacin show an enlargement of the hock joints, perosis, dermatitis, retarded growth, and an inflammation of the mouth and tongue (see Table 7.13). In addition to these symptoms, poor feathering and hyperirritability may be observed.

Pantothenic Acid (Vitamin B_3)

Pantothenic acid is added to poultry diets to ensure against any possibility of deficiency (for required and recommended levels see Table 7.14). Pantothenic acid is important to multiple intracellular processes being critical to the synthesis of coenzyme A (see Table 7.12). Symptoms of pantothenic acid deficiencies in chicks are somewhat nonspecific, including reduced growth, poor feathering, liver damage, and lesions around the beak, eyes, and vent (see Table 7.13). Lowered hatchability and a high mortality rate of newly hatched chicks can result from feeding hens a diet deficient in pantothenic acid.

Riboflavin (Vitamin B_2)

Poultry feeds should be supplemented with riboflavin (see Table 7.14). Riboflavin is important to cellular metabolism either as flavin mononucleotide or flavin adenine dinucleotide (see Table 7.12). Both flavin mononucleotide or flavin adenine dinucleotide play critical roles in electron transport (linked to cellular ATP production) or as a co-factor for some reactions alone and some with vitamin B_6 (pyridoxal phosphate). Chicks suffering from a riboflavin deficiency display a characteristic curled-toe paralysis as well as depressed growth and diarrhea. In curled-toe paralysis, the brachial and sciatic nerves become greatly enlarged. Poor egg production and hatchability are observed in riboflavin-deficient hens (see Table 7.13).

Thiamin (Vitamin B_1)

The requirement for thiamin is moderate in poultry with it needing to be added to poultry feeds (see Table 7.14). Thiamin pyrophosphate is an important coenzyme for specific enzymic reactions including pyruvate dehydrogenase (pyruvate to acetyl coenzyme A in metabolizing glucose) and α-ketoglutarate dehydrogenase (glucose oxidation in the citric acid cycle) (see Table 7.12). Thiamin-deficient birds show polyneuritis, a type of paralysis. Prior to this acute deficiency condition, anorexia, emaciation, ruffled feathers, and incoordination are observed (see Table 7.13). When polyneuritis sets in, a progressive paralysis is observed, beginning first in the toes and ultimately reaching the head, whereupon the head is retracted so that it lies on the back. Deficient adults frequently have a blue comb.

Vitamin B_6 (Pyridoxine, Pyridoxal, Pyridoxamine)

Pyridoxine is added to poultry feed. It is required as a co-enzyme, allowing enzymic reactions and for the synthesis of neurotransmitters, such as serotonin and norepinephrine (see Table 7.12). Deficiencies of pyridoxine have marked effects in poultry (see Table 7.13). Symptoms in chicks are depressed growth and neurological problems such as poor coordination and convulsions. Mature birds deficient in vitamin B_6 exhibit anorexia, loss of weight, and reduced egg production and egg hatchability.

Vitamin B_{12} (Cobalamin)

Vitamin B_{12} is found only in animal products and some products of bacterial fermentation. Consequently, poultry feeds need to be supplemented with vitamin B_{12}. Vitamin B_{12} plays a critical role in maintaining the functioning of poultry as it does in livestock and people. It is very important in erythrocyte formation, in DNA synthesis, and as a coenzyme maintaining the functioning of nerves and other tissues (see Table 7.12). Liver stores of vitamin B_{12} may be high enough to sustain adult poultry for several months, but high-protein diets can accelerate this depletion process. Birds deficient in vitamin B_{12} exhibit poor feed conversions, depressed growth, reduced hatchability, and in some cases perosis (slipped tendon) (see Table 7.13). Fatty livers, kidneys, and hearts can be observed in some deficient birds. Vitamin B_{12} deficiency is associated with depressed growth.

7.10 Water Requirements

Poultry should have free access to clean, fresh water at all times, as it is integral to their organs and tissues. It can be viewed as a component of the organ structures, critical for blood flow and blood pressure, ensuring that the enzymes are functional, and has a role as a solvent, a lubricant, and an important part of the mechanism to control body temperatures. A general rule is that chickens drink approximately twice as much water by weight as the feed they consume.

Water Balance in Broiler Chickens

Considering raising a 2.3 kg (5.1 lb) broiler:

- Water intake between hatching and marketing—6.3 liters (1.7 gallons).
- Water output (excreta and exhaled air) between hatching and marketing—4.9 liters (1.3 gallons) of water.
- Water retention in body—1.4 liters (0.4 gallons).

The amount of water required by poultry varies considerably. The factors that affect the amount of water birds will consume are age, body weight, production, environment/weather (with increased water required to counter-balance that lost through panting at elevated environmental temperatures and humidity), and diet. The intensity of production dramatically affects the water requirements as more is needed with the feed and as there is more in the tissues.

Water is the largest single constituent of poultry tissue; it constitutes 85% of the body of a day-old chick, 58% of the body of an adult bird, and 66% of an egg. Yet, water is often neglected. Birds can lose 98% of their body fat or 50% of their body protein and still survive. However, a 10% loss in body water causes serious physiological disorders, and 20% loss in body water will cause death. In addition to being readily available, water quality is important. Water should be tested to determine that salts, pesticides, and microorganisms are at acceptable levels and that the water is palatable to poultry. Water that adversely affects growth, reproduction, or productivity should not be used.

7.11 Antinutritive Factors in Feeds

Some feedstuffs may contain toxic compounds. Examples include the following:

- Gossypol is found in cottonseed meal. It depresses growth rate, reduces feed conversion efficiency in young ducks, and also discolors the yolks of eggs.
- Fava beans (*Vicia faba* L.) contain antinutritive factors including tannin and some protease inhibitors.
- Some strains of rapeseed meal contain high enough goitrogenic compounds to be toxic.
- Soybean meal contains harmful substances such as trypsin inhibitor, but these are destroyed by sufficient heating.
- Some cereals such as wheat, barley, and rye contain nonstarch polysaccharides, including pentosans and β-glucan. These increase the viscosity of the ingesta and, consequently, reduce both digestion and nutrient absorption. They are considered antinutritive factors.

Specific enzymes are very useful in breaking down antinutritive factors and are added to poultry feeds (discussed in Chapter 8).

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8

Feeds, Feedstuffs, Supplements, and Additives

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List the major categories of feedstuffs.
2. Know what the different sources of energy are to poultry feeds.
3. Know where the sources of energy for poultry feeds are produced.
4. List the major feedstuffs providing protein for poultry diets and advantages and disadvantages of each.
5. Know where the sources of protein for poultry feeds are produced.
6. List the sources of minerals for poultry diets and advantages and disadvantages of each.
7. Know why vitamin and/or trace elements are added to poultry feeds.
8. Understand the major by-products used in poultry diets and advantages and disadvantages of each.
9. List the major additives used in poultry diets and the purpose of each.
10. Discuss the major methods of evaluating poultry feedstuffs and diets.

8.1 Introduction to Feedstuffs Used in Poultry Feeds

The economic importance of poultry feeds is clear; more than half of the total production cost of poultry is from feed. Therefore, the efficient use of feed is vital to poultry production. The major objective of poultry feeding is to convert feedstuffs into human food. In this respect, the domestic fowl is very efficient. A wide variety of feedstuffs can be used in poultry feeds (see Figure 8.1), which may be classified as energy feedstuffs (cereals; for composition see Table 8.1), proteins supplements (for composition of different feedstocks see Table 8.2), specific amino-acid supplements, mineral supplements, vitamin supplements, and other non-nutritive additives.

8.2 Energy Feedstuffs—Cereals/Grains

The major energy sources for poultry feeds are cereal grains, their by-products, and fats. The composition of grains is summarized in Table 8.1, while the protein composition of different feedstuffs is shown in Table 8.2. The production of seed grain in the United States consists of corn (95.3%; over 15 billion bushels), sorghum (3%), barley (1.3%), and oats (0.4%).

Figure 8.1 Young turkeys eating. (Photo courtesy of the Iowa Turkey Federation)

Conversion from Bushels to Metric Tons

Corn or sorghum: 39.4 bushels = 1 metric ton
Barley: 45.9296 bushels = 1 metric ton
Wheat or soybeans: 36.74 bushels = 1 metric ton

Corn/Maize

Corn/maize is the most important grain used by poultry and other livestock, both globally and in the United States. This can be explained by the nutrients corn provides, including readily digestible carbohydrates (starch and sugars) together with oils and protein (Table 8.1). Starch and oils provide energy to poultry and other livestock for growth, egg production, and maintenance. The protein is available for growth and egg production. There is a plentiful supply of corn due to the efficiency of production (see Table 8.3).

Table 8.1 Composition of cereals used in poultry feed.

	Corn (Yellow Dent Corn)	Grain Sorghum	Wheat	Barley	Rye	Pearl Millet	Triticale
Available CHO[1]	72 (75 +1.7)	63	70	56	72	63	62 (59.5 + 5.2)
Protein	8.9	8.3	10.6	11.0	8.7	11.5	11.4
Oil	4.0	3.9	1.9	3.4	1.5	4.7	1.7
Fiber	8.0	4.1	1.0	3.7	2.2	1.5	3.2
Ash	1.5	2.6	1.4	1.9	1.8	1.5	2.0

[1] Available carbohydrate (starch and sugars).

Data from the Food and Agriculture Organization.

Table 8.2 Protein composition of different feedstuffs (g per kg).

Feedstuff	Dry Matter	Crude protein (N × 6.25)	Lysine	Methionine	Threonine
Meat and bone meal	982	581	38.0	9.3	19.5
Soybean meal	927	475	30.4	1.7	18.2
Canola meal	958	405	23.2	6.7	16.1
DDGS	978	261	9.8	5.6	10.1
Wheat	940	113	3.7	1.8	3.3
Corn	918	91	3.8	1.7	3.2

Based on Kong and Adeola, 2010.

Textbox 8A

A Deeper Dive: The Carbohydrates in Cereals and Legumes

Cereals and legumes contain different types of polysaccharides. The most important for poultry nutrition is starch supplying energy.

Starch is located within granules made up of both amylose and amylopectin molecules. The chemistry of starch is discussed in Chapter 7. Starch can be digested in the gastrointestinal tract of poultry and other animals to various extents based on the different types of starch. Textbox 8A Table 1 summarizes results for a study covering both the content of starch and their digestibility in different cereals and legumes. In addition to starch, there are other carbohydrate constituents that cannot be digested, including phytate and the cell wall complex carbohydrates hemicellulose, β-glucan, and cellulose.

Phytate is an important storage form of phosphate in plant seeds (grain). Phytate is a salt of phytic acid; it contains six phosphates per molecule and binds (chelates) calcium. Phytic acid (*myo*-inositol 1,2,3,4,5,6-hexakisphosphate) (InsP6) is inositol with six phosphates covalently bound. Inositol consists of six carbon atoms in a ring; each carbon atom has a hydroxyl group (with total of 6 hydroxyl groups). Inositol is a key component in phospholipids in poultry and other animals. The phosphate in phytate is largely unavailable to poultry and other animals and passes through the gastrointestinal tract and into the feces. Moreover, bound calcium has a reduced availability.

Hemicellulose (beta-1,4-xylan or simply xylan) is a linear polysaccharide made up of multiple monosaccharides, specifically xylose units. The name "xylan" derives from "xylon," the Greek word for wood. Wheat has a high xylan content.

β-glucan is a polysaccharide composed of multiple monosaccharides, specifically glucose units. Barley has a high content of β-glucan.

Cellulose is also a polysaccharide composed of multiple monosaccharides, again specifically glucose units. The glucose units are linked in a β manner.

Textbox 8A Table 1 Differences in both the content and digestibility of starch in cereals and legumes.

Cereal/Legume	Starch (g per kg)	Digestibility (%)
Corn (maize)	610	97.4
Wheat	539	93.8
Barley	488	98.3
Sorghum	616	95.4
Common Beans	311	74.5
Peas	373	81.0

Data from Weurding et al., 2001.

Table 8.3 Yield (metric tons per hectare) of various poultry feedstuffs in 2016.

Feedstuff	World	USA	China
Cereals			
Barley	3.0	4.2	4.3
Corn/maize	5.6	11.0	5.9
Sorghum	1.4	4.9	4.5
Tritale	3.7	—	1.8
Wheat	3.4	3.5	5.4
Protein Sources			
Oil seed rape	2.0	2.0	2.0
Soybeans	2.8	3.5	1.8

Definitions: metric ton (in UK called the tonne) = 1000 kg or megagram (Mg) = 1.1 US ton or 0.98 Imperial ton. Hectare = 10,000 square meters = 10^4 m^2 = 2.47 acres.

Data from FAOStat.

The Names of Corn or Maize

According to the *Oxford Dictionary*, in the United States, Canada, Australia, and New Zealand the word *corn* is synonymous with *maize*. However, in the UK, *corn* refers to the prevalent cereal; this being wheat in England and oats in Scotland. An alternative meaning of wheat in the UK is the grain of cereals. The word *maize* comes from the Spanish *maíz*, which comes from the word *mahiz* of the now-extinct language of the Taino people (of the Bahamas and Florida). The word *corn* comes to English from Anglo-Saxon and, in turn, from Proto-Germanic for "a small seed."

Corn/maize (*Zea mays*) was domesticated in Central America about 4500 years ago. In 2017, Global production of corn/maize was 1.13 billion metric tons. The top producing countries are the United States with 0.37 billion metric tons (14.60 billion bushels) and China with 0.26 billion metric tons (10.12 billion bushels). Figure 8.2 shows stages of corn production. There are about 90 million acres (36.4 million hectares) used per year in corn production in the United States. Corn production is focused in the US Heartland states (the Corn Belt) including the contiguous states of eastern South Dakota, Nebraska, Iowa, northern Missouri, Illinois, Indiana, Ohio, and parts of Kentucky.

Corn produced in the United States is used for ethanol (40%), poultry and livestock (36%; predominantly for poultry), and export (24%; much going to feeding poultry and livestock). Corn is used in poultry feed after grinding. In addition, corn is either wet- or dry-milled. Dry-grind ethanol production consists of the following steps:

1. Dry grinding whole grain.
2. The addition of water to produce a slurry.
3. Cooking.
4. Hydrolyzing starch and fermentation.
5. Recovery of ethanol.
6. Recovery of nonfermentable components in corn (germ, fiber, protein) as distillers dried grains with solubles (DDGS).

Wet milling is summarized in Figure 8.3.

Dry-grind ethanol production results in two products: (1) ethanol and (2) corn distillers dried grains with solubles (DDGS) (use as a feedstuff is discussed below under cereal-milling by-product feeds). Corn supplies about 60% of the total feed in corn/soybean diets. Grains contain starch, sugars, fats (oils), proteins, fiber, and ash. The constituents of corn come

A. Growing corn/maize. (Source: TB studio/ Shutterstock)

B. Corn cobs include corn grain. (Source: COLOA Studio/ Shutterstock)

C. Corn grain. (Source: Jesus Cervantes/ Shutterstock)

Figure 8.2 Corn/maize production.

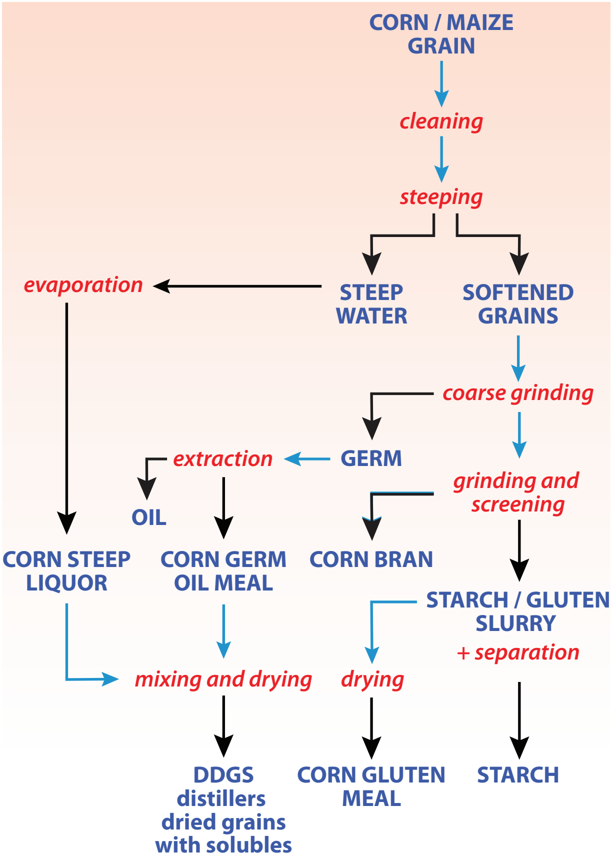

Figure 8.3 A schematic diagram of the wet milling of corn.

from different parts of the seed: starch is predominantly in the endosperm; protein oil, sugars, and ash are predominantly in the germ; and fiber is predominantly in the bran coat and tip cap.

Wheat and Barley

Wheat and barley can be used instead of corn depending on availability and price (for yields see Table 8.3). Globally, 771 million metric tons of wheat were produced in 2017 with the vast majority going to food for people. Wheat and barley are lower in energy than corn, but higher in protein (see Tables 8.1 and 8.2). When used without enzyme supplementation, wheat and barley are gelatinous and have a tendency to "paste" on the beaks. With enzyme supplementation, wheat or barley can substitute for corn. In the absence of enzymes, either wheat or barley are often coarsely ground and pelleted when fed at high levels.

Sorghum

Sorghum grains can be used in poultry feeds. Sorghum (*Sorghum bicolor*) was domesticated in Northeastern Africa about 10,000 years ago. Throughout the world, production of sorghum in 2016 was 63.9 million metric tons. The top global producers were the United States (12.2 million metric tons, with 75% exported and 15% used for poultry and livestock feed), Nigeria (6.9 million metric tons), and Sudan (6.5 million metric tons). Other major producers include Mexico (5.0 million metric tons), India (4.4 million metric tons), Ethiopia (4.8 million metric tons) and China (2.4 million metric tons). Figure 8.4 shows sorghum production. In the United States, sorghum is grown primarily in the States of Texas, Oklahoma, Kansas, Colorado, and South Dakota. There is also increases in sorghum production in Arkansas and Missouri. The yield of sorghum is high on relatively dry land (see Table 8.3).

Sorghum contains similar levels of protein and oil to corn and is also high in available carbohydrate, albeit somewhat lower than in corn (see Table 8.1). Sorghum grains can be substituted in place of corn as an energy feed depending on price but there are undesirable effects on poultry performance.

Rye

Rye can be used in poultry feeds particularly when enzymes are added to the feed. Without these, feeds containing rye are relatively unpalatable and are accompanied by sticky, pasty droppings. When used without enzyme supplementation, rye should not replace more than one-fourth of the cereal grains in the feed of young chicks; for older birds, rye should not replace more than one-third of the cereal grains unless supplemented with enzymes.

Other Grains

Rice can be used effectively in poultry feed. Milled rice is quite comparable to corn in feeding value except that it is lacking in vitamin A activity and pigmenting qualities. **Triticale** is a hybrid of wheat and rye. Production of triticale is associated with high yields of grain (Table 8.3). Triticale can be used as a replacement for corn or wheat. It contains less available carbohydrate and oil than either corn or wheat but more protein (Table 8.1).

Millet can be substituted for corn in poultry feed. It has lower available carbohydrate than corn but

TEXTBOX 8B

A Deeper Dive: Comparing Wheat and Corn on Broiler Performance Together with Use of the Enzyme Xylanase

Wheat-based diets contain non-starch polysaccharide (NSP) including pentosans and β-glucan. These are said to increase the viscosity of the ingesta; decreasing nutrient absorption and digestion (Sheng et al., 2013). Textbox 8B Table 1 shows that ingesta in the jejunum from young broiler chickens on a wheat-based diet have a higher viscosity than in those on a corn diet. Interestingly, performance was superior in this study for birds on the wheat-based diet than those on a corn-based diet. This is illustrated by a study summarized in Textbox 8B Table 1.

The impact of indigestible polysaccharides, particularly in wheat-based diets, was assessed by the inclusion of the enzyme xylanase, produced by the genetically modified microorganism *Trichoderma reesei*. Xylanase clearly increased growth and feed gain efficiency in broiler chickens on a wheat-based diet but had little effect on those on a corn-based diet (Kiarie et al., 2014)

Textbox 8B Table 1 Effect of corn- and wheat-based diets together with the effects of xylanase (endo-1,4-β-xylanase) in broiler chickens between days 22 and 42.

	Corn (No Xylanase)	Corn (Xylanase)	Δ (%)	Wheat (No Xylanase)	Wheat (Xylanase)	Δ (%)	SEM
Gain (g)	1,458[a]	1,501[a]	+43 (+2.9)	1,707[b]	1,922[c]	+215 (+12.6)	27.8
Feed Intake (g)	3,738[a]	3,751[a]	+13 (+0.3)	4,056[b]	4,235[b]	+179 (+4.4)	117
Feed to Gain	1.964[a]	1.920[a]	• 0.044 (−2.2)	1.853[b]	1.703[c]	• 0.150 (8.1)	0.022
Jejunal Viscosity	3.7[b]	2.4[a]	• 1.3 (• 35.1)	5.2[c]	2.2[a]	• 3.0 (• 57.7)	0.3

[a, b, c] Different superscript letters indicate difference $p < 0.05$.

Based on Kiarie et al., 2014.

A. Sorghum growing. (Source: Toppy Baker/Shutterstock)

B. Sorghum grain. (Source: matin/Shutterstock)

Figure 8.4 Sorghum production.

TEXTBOX 8C

A Deeper Dive: Using Barley and Rye in Feed and Enzymes

Barley- or rye-based diets are associated with reduced weight gain in broiler chickens and lower feed intake, increased viscosity of the ingesta and decreased amino acid digestibilities (Almirall et al., 1995). Non-starch polysaccharides (soluble fiber), such as arabinoxylan in barley- and rye-based diets, increase the viscosity of injesta and thereby depress digestion and absorption with decreased amino acid fecal digestibilities (Almirall et al., 1995; Choct, 1997; Scheller and Ulvskov, 2010).

The use of rye in poultry diets is limited because of its negative effects on bird performance compared to a corn-based diet. However, the adverse effects are largely overcome by the addition of beta-glucanase and xylanase to the feed. Growth is improved as is feed: gain efficiency. At least part of the reason that rye is poorer than corn is the high viscosity of the ingesta (Textbox 8C Table 1). Again, this is overcome, albeit partially, by supplementing the feed with beta-glucanase and xylanase. Similarly, addition of the enzyme, β beta-glucanase, to barley-based diets decreases the viscosity of ingesta (Almirall et al., 1995).

Textbox 8C Table 1 Effect of using rye or rye plus beta-glucanase and xylanase between days 4 to 24.

	Corn	Rye No Enzyme	Rye + β-Glucanase and Xylanase
Growth (Body Weight Gain as g per Day)	40.1[a]	31.7[b]	38.3[a]
Feed Consumption (as g per Day)	66.5[a]	63.6[b]	66.7[a]
Feed Gain Efficiency	1.66[a]	1.96[b]	1.71[a]
Intestinal Viscosity (Centipoises)	5[a]	465[c]	121[b]

[a, b, c]Difference superscript letter indicates difference $p < 0.05$.

Based on Lázaro et al., 2003.

higher protein (Table 8.1). **Oat** grains can also be used in poultry feeds. Oats are lower in energy than corn and are usually not cost effective for broiler and layer feeds.

8.3 ENERGY FEEDSTUFFS—CEREAL-MILLING BY-PRODUCT FEEDS

Numerous by-products result from the milling and processing of grain. Wet milling creates steepwater, germ, gluten meal, gluten feed, and native starch. Dry milling creates grits and cones, hominy feed (livestock feed), flour, and germ. Many contain high amounts of protein as well as energy, such as corn gluten meal (see Figure 8.3).

Distillers Dried Grains with Solubles (DDGS)

A by-product of ethanol production from corn is distillers dried grains with solubles (DDGS) (see Figure 8.3). DDGS are good sources of protein for poultry feeds. In addition, DDGS provides some energy as oil (Table 8.4). Other grains, such as barley, are used in the brewing of beer, while rye and corn are used to produce various liquors (whiskeys). After processing, the remaining by-product (brewers and distillers grains) can be readily adapted to many feeding programs.

Table 8.4 Composition of distillers dried grains with solubles (DDGS).

	DDGS
Dry Matter (%)	88
Crude Protein (%)	27
Crude Fat (%)	11
Ash (%)	5
Phosphorus (%)	0.7
Total Fiber	34.5

8.4 ENERGY FEEDSTUFFS—FATS/OILS

Animal and vegetable fats are now used extensively in poultry feed. They increase the caloric density of the ration, control dust, reduce the wear and tear on feed-mixing equipment, facilitate pelleting of feeds, increase palatability, and help homogenize and stabilize certain feed additives, especially those of a very fine particle size. However, the use of fats in poultry feeds requires good mixing equipment. Also, it is necessary that the fat be properly stabilized in order to prevent rancidity. Chickens are capable of utilizing fats. Fat is added to poultry feed to meet the energy needs of the birds. A maximum of 5% fat is usually added to poultry feed due to its costs (see Chapter 7).

8.5 Other Energy Feedstuffs—By-Products (e.g., Molasses, Glycerin)

Molasses

Molasses (known as black treacle in the UK) is a by-product of manufacturing sugar from either sugar cane or sugar beet (see Figure 8.5). As such, molasses consists of the simple sugars (about 75%), namely glucose and fructose (monosaccharides) and sucrose (disaccharide; about 75%), along with water and impurities. Molasses can be used effectively as an energy feed in poultry feeds. Excessive amounts cause

Figure 8.5 Molasses can be added to poultry feed. Globally, 61.0 million metric tons of molasses were produced in the world in 2014. (Source: MOAimage/Shutterstock/)

wet droppings and, hence, molasses levels are generally restricted to 2–5%. In addition to its use as an energy feed, molasses reduces the dustiness of the feed and acts as a binder for pelleting.

Glycerin

Glycerol [glycerin(e)—$CH_2OH.CHOH.CH_2OH$] is a by-product of biodiesel production or from processing oilseed rape/canola. It is a high energy supplement with a gross energy of 4,100 kcal per kg and an apparent metabolizable energy (AME) of 3,621 kcal per kg. Raw glycerol has been shown to be an effective supplement to poultry diets, replacing some of the fat. It should be noted that raw glycerin may contain some methanol.

8.6 Protein Supplements

The usefulness of a protein feedstuff for poultry depends upon its ability to furnish the essential amino acids, the digestibility of the protein, and the presence of antinutritive factors. Both vegetable and animal protein supplements are used for poultry. Most of the protein supplements contribute minerals and vitamins. Grain has relatively low concentrations of protein (see Tables 8.1 and 8.2), however with the amount in the feed, say 60%, grain proteins are providing a significant amount of protein. The protein requirements are completed by the addition of oilseed meal.

8.7 Oilseed Meals

Global production of oilseeds is summarized in Table 8.5. This is produced from palms, grain crops, and oilseeds; the latter including the following:

- Soybeans producing soybean oil. Top producers of soybean oil in 2018 were the following: (1) China, 16.13 million metric tons; (2) United States, 10.78 million metric tons; (3) Brazil 8.54 million metric tons; and (4) Argentina, 7.24 million metric tons
- Canola (North American term)/oilseed rape (European term) producing canola oil (see Figure 8.6). Top producers of oilseed rape are (1) EU, 9.4 million metric tons; (2) China, 6.3 million metric tons; (3) Canada, 4.2 million metric tons; (4) India, 2.6 million metric tons; and (5) Japan, 1.1 million metric tons.
- Sunflowers producing sunflower oils.

Other oilseeds are cotton, linseed, peanut, safflower, and sesame.

These are used for two major purposes: oil and protein. The oil is used for vegetable oils for human food (vegetable oil for cooking together with margarine and shortening after hydrogenation), and as a feed stock for the production of biodiesel, paints, and other industrial purposes. Parenthetically, vegetable oil is also obtained from corn. These oilseeds are valuable sources of proteins for use in poultry feed, pig feed, and human foods (e.g., tofu). Oil is extracted from these seeds by one of the following basic processes or modifications thereof: solvent extraction, hydraulic extraction, or expeller extraction.

Table 8.5 Global oil seed production in 2017.

Oilseed	Production in Million Metric Tons
Soybean	353
Oilseed rape/rapeseed/canola	76.2
Sunflower seed	47.8
Sesame seed	5.5
Linseed	2.8
Castor oil seed	1.8
Safflower seed	0.8

Data from FAOStat.

Soybeans

Soy (referred to as "soya" in some countries) beans (*Glycine max*) were domesticated about 5000 years ago in the region of East Asia that is present-day China. Soybean production is focused in the United States and China, along with Brazil and Argentina. Production of soybeans is efficient with relatively high yields (Table 8.3). Soybean production is illustrated in Figure 8.7. Table 8.6 shows the composition of soybeans and soybean meal. About 85% of the global production of soybeans is processed or crushed, generating oil (see Table 8.7 for fatty acid combination) and soybean meal (over 90% going to feed for poultry and livestock).

Figure 8.6 Canola production.

A. Canola/oilseed rape field. (Daniel Prudek/Shutterstock)

B. Canola oil. (Source: Jeffrey B. Banke/Shutterstock)

A. Soybeans growing. There were 307 million metric tons of soybeans produced in the world in 2014. (Source: GreenMiles/Shutterstock)

B. Mature soybeans. (Source: domnitsky/Shutterstock)

C. Soybeans are an excellent source of protein for poultry after crushing (extraction of oil and heating). (Source: Cq photo juy/Shutterstock)

Figure 8.7 Soybean production.

Table 8.6 Composition of de-hulled soybeans and soybean meal.

Component	De-Hulled Soybeans	Soybean Meal (Oil Extracted)
Protein	40	48
Lipid/fat	20	< 1
Carbohydrate	30	35–40
Ash	4	5-6
Water	6	7–10

Data from USDA, 2016.

Soybeans are cleaned and dehulled prior to processing. The techniques to process soybeans are (1) solvent (hexane) extraction of flaked soybeans, (2) continuous pressing combined with increased temperatures, (3) hydraulic or batch pressing combined with increased temperatures of flaked soybeans, and (4) extrusion.

Soybean meal is the most widely used key protein component in poultry feeds. This is due to its high protein content and the efficient production of the plant source (see Table 8.6). Unlike many plant products, the relatively high carbohydrate contents in soybeans and soybean meal are not due to the presence of starch. Instead, about half the carbohydrates in

Table 8.7 Differences in the fatty acid composition of corn oil, canola oil, and soybean oil.[1]

Fatty Acid(s)	Corn Oil	Canola	Soybean Oil (Not Hydrogenated)
Saturated	**13.1**	**6**	**14**
Palmitic	10.5	4	10
Stearic	1.8	2	4
Arachidic	0.4	—	—
Monounsaturated	**26.0**	**56**	**23**
Oleic	26.0	56	23
Polyunsaturated	**59.7**	**36**	**58**
Linoleic	57	26	51
Linolenic	1	10	7
Other	**1.2**	**4**	**5**

[1] There are marked differences in the fatty acid composition of different vegetable oils/seeds used in poultry feeds.

soymeal are soluble sugars (small oligosaccharides) and much of the rest is large non-starch polysaccharides. These are largely not digested in the small intestine of poultry. However, they are fermented by microorganisms, for instance in the ceca of the bird, to generate volatile fatty acids and other metabolites that can be used by the bird. Because raw soybeans contain several antinutritional factors, they should not be fed directly to poultry. If heat-processed, however, soybean meal is very acceptable in poultry feeds.

Canola/Oilseed Rape Meal

Canola (or oilseed rape) is grown extensively throughout the world with total global production being 71.3 million metric tons in 2017. In the past, meal made from unimproved rape was rather unpalatable and contained goitrogenic compounds that are hazardous to poultry. Canola was developed with low levels of glucosinolates and erucic acid (a long-chain fatty acid) in the oil.

Canola is grown in the temperate zone with the top producers being China 5.7 million metric tons, Germany 3.5 million metric tons, Canada 3.1 million metric tons, India 2.5 million metric tons, and France 1.9 million metric tons. Average yield globally for canola is less than soybeans (see Table 8.3). Canola is also produced in some states in the United States (e.g., North Dakota). Canola meal averages about 40% crude protein (Table 8.2) and its amino acids compare favorably with soybean meal. When the price is favorable, canola meal may be used as a protein supplement for poultry.

Other Oilseeds

Coconut Meal (Copra Meal)

This is the by-product from the production of oil from the dried meats of coconuts. Coconut meal averages about 21% protein content. When copra meal is fed to poultry, it should be supplemented with the amino acids lysine and methionine. Supplemented copra meal can make up to 20% of poultry feed.

Cottonseed Meal

Globally, 47 million metric tons of cottonseed are produced (Table 8.5). Oil and high protein meat (22%) are separated. Cottonseed meal is low in lysine and tryptophan and deficient in vitamin D, carotene (vitamin A value), and calcium. Also, it can contain toxic substances known as gossypol and cyclopropenoic fatty acids. Improved cottonseed has much lower levels of antinutritive factors. Cottonseed meal can be fed to poultry.

Linseed Meal

About 2.9 million metric tons of linseed are grown globally in 2016 (Table 8.5). Linseed meal is the residue remaining after the oil extraction and averages about 35% protein content (33 to 37%). It can have a laxative effect and can depress growth in poultry. Hence, linseed meal levels should be no higher than 5% of the poultry diet.

Peanut Meal

Peanut meal is a by-product of the peanut industry that consists of ground peanut cake; the product remaining after the extraction of the oil. Peanut meal ranges from 41 to 50% protein and from 4.5 to 8% fat. It is low in methionine, lysine, tryptophan, calcium, carotene, and vitamin D. Peanut meal tends to become rancid when held too long.

Safflower Seed Meal

Global production of safflower was 0.95 million metric tons in 2016 (Table 8.5). Most safflower meals contain seeds with part of the hull removed, yielding a product of about 15% fiber and 40% protein. Safflower meal is deficient in lysine and methionine. Safflower meal may be used in layer feeds at levels up to 15%.

Sesame Meal

Global production of sesame seeds was 6.1 million metric tons in 2016 (Table 8.5). Sesame is one of the oldest cultivated oilseeds. The sesame meal is produced by either solvent extraction or pressing. Solvent extraction yields higher protein (45%) but lower fat levels (1%) than either the screw press or hydraulic methods, which produce meals containing about 38% protein and 5 to 11% oil. Sesame meal is extremely deficient in lysine. It is recommended that some soybean meal, along with added lysine, be fed along with sesame meal to achieve optimal performance.

Sunflower Oil

Globally, 47.3 metric tons of sunflower seeds were produced in 2016. Sunflower meal is a high-quality

TEXTBOX 8D

A Deeper Dive: Digestibility of Feedstuffs

There are marked differences in lysine digestibility of different feedstuffs as shown in Textbox 8D Table 1 for broiler chicks and Textbox 8D Table 2 for ducklings. For instance, in broiler chicks, soybean and fish meal have higher lysine digestibilities than for canola which, in turn, has a higher lysine digestibility than DDGS (distillers dried grains with solubles) or feather meal. Similarly, soybean and fish meal have higher lysine digestibilities than for canola or DDGS.

Textbox 8D Table 1 Differences in digestibility of different feedstuffs.

Feed	Standardized Lysine Digestibility in Cecectomized Adult Male Chickens (%)	Apparent Ileal Digestible Lysine in Chickens (%)
Soybean meal	90	84
Fish meal	88	83
Blood meal	87	—
Sunflower	84	—
Canola	80	72
Meat and bone meal	80	58
Poultry by-product meal	80	—
Cottonseed meal	67	55
DDGS (Distillers dried grains with solubles)	67	—
Feather meal	65	54

Ravindran et al., 1998; Parsons, 2005.

Textbox 8D Table 2 Apparent ileal digestibility (%) of different feedstuffs in White Pekin young ducks (19 days old).

Feedstuff	Dry Matter	Nitrogen	Lysine	Methionine	Threonine
Soybean meal	79.6	88.3	90.3	91.4	91.4
Corn	79.0	74.8	78.0	85.6	61.6
Meat and bone meal	77.0	72.4	75.6	78.4	78.4
Wheat meal	72.2	78.8	76.7	84.7	84.7
Canola meal	64.9	76.0	79.0	84.8	84.8
DDGS	63.0	77.3	69.2	85.0	85.0

Based on Kong and Adeola, 2010.

source of plant protein used in both North America and Europe. Sunflower oil meal varies depending on how it is processed and whether the seeds are dehulled. Meal from pre-pressed solvent extraction of dehulled seeds contains about 44% protein, as opposed to 28% for whole seeds. Screw-pressed sunflower meal ranges from 28 to 45% protein. When sunflower meal is used in poultry feeds, it should be combined with lysine supplements and pelleted or crumbled to prevent stickiness and necrosis of the beak.

8.8 Animal Proteins

Protein supplements of animal origin are derived from (1) meatpacking and rendering operations, (2) poultry and poultry processing, (3) milk and milk processing, and (4) fish and fish processing. With further improvement in the protein quality of plants, such as the development of high-lysine corn and synthetic amino acids, the use of animal proteins may decline in the future. Moreover, there has been considerable consumer resistance to animal products in poultry feed and large integrators are eliminating animal proteins for poultry feed.

Fish Meal

Fish meal is a by-product of the fisheries industry. It consists of dried, ground whole fish or fish cuttings with or without extraction of the oil. The nutritive value of fish meal varies by the (1) method of drying; (2) type of fish used, such as menhaden, sardine, herring, salmon, and white fish (e.g., cod and haddock); and (3) amount of oxidation (ethoxyquin is added to fish meal to prevent oxidation). Fish meal varies in protein content from 57 to 77%. The protein is high value, providing the necessary amino acids for poultry, and is 92 to 95% digestible. If fish meal is poorly processed or improperly stored, the digestibility of protein decreases dramatically.

8.9 Yeast

Yeast can be a protein supplement. Three forms of dried yeast are used in poultry feeding: (1) dried yeast (35% protein), which is a by-product of the brewing industry; (2) torula yeast, resulting from the fermentation of wood residue and other cellulose sources; and (3) irradiated yeast.

8.10 Amino Acid Supplements

L form amino acids such as L-lysine and threonine are produced by microorganisms; these are frequently genetically modified microorganisms. These amino acids are purified and are added to poultry feeds so that the requirements of specific essential amino acids are met. Crystalline amino acids are close to 100% utilizable. Feeds are supplemented with sulfur amino acids by the addition of chemically synthesized compounds, namely DL-Methionine or DL-Methionine-hydroxy analog [DL-2-hydroxy-(4-methylthio) butanoic acid] or their salts. These are broadly equivalent in meeting the needs of methionine in poultry diets.

8.11 Mineral Supplements

Mineral supplements are required by poultry for systems and cellular functioning of poultry together with skeletal development of growing birds and for egg (eggshell) formation of laying hens. The macrominerals required by poultry, namely salt (sodium chloride), calcium, magnesium, potassium, and phosphorus (phosphate) are routinely added to poultry feed, as are trace minerals. This is accomplished through the use of a commercial trace mineral mix.

Calcium and Phosphorus Supplements

The common **calcium** supplements used in poultry feeding are ground limestone, crushed oyster shells or oyster flour, bone meal, calcite, chalk, and marble. Most of the **phosphorus** in plant products is in organic form (as phytate phosphate) and are not well utilized by young chicks or turkey poults. There needs to be an emphasis on inorganic phosphorus sources in the formulation of poultry feed. The most important inorganic phosphorus sources in poultry feeding are (1) dicalcium phosphate, (2) defluorinated rock phosphate (The Association of American Feed Control Officials has established maximum fluorine content), and (3) steamed bone meal. These supplements supply both calcium and phosphorus. It should be noted that phytate phosphorus is unavailable to poultry and other simple-stomached animals because of a lack of the enzyme phytase in the gastrointestinal tract. The enzyme can be added to poultry feeds (discussed below under additives). In plants, approximately one-third of the phosphorus has been found to be present as nonphytate phosphorus and is available to chickens. In calculating the available phosphorus content of feed, the phosphorus from inorganic supplements and animal feedstuffs is considered to be 100% available while that from plants is assumed to be 30% available.

8.12 Vitamin Supplementation

As with minerals, poultry feeds should be supplemented with vitamins. While the requirements of vitamins are extremely low in comparison with energy and protein, the omission of a single vitamin from the diet will have severe consequences (acute or subacute deficiencies). Supplementation with a vitamin pre-mix is critically important irrespective of what is present in different feedstuffs and very cost effective. Pre-mixes frequently contain both trace minerals and vitamins. Parenthetically, it is noted that vitamins may be destroyed by heat, sunlight, oxidation, and mold growth; so freshness is important.

For some niche poultry products, alfalfa, hay, or leaf meal can be included to supply vitamin A, riboflavin, vitamin E, vitamin K, minerals, and protein. Dehydrated alfalfa meal is superior to sun-cured meal because of its higher vitamin content. Leaf meal is better than hay because of its lower fiber and greater nutrient content.

8.13 Non-Nutritive Additives

Poultry feeds contain non-nutritive feed additives. These additives are used for a variety of reasons. They are not nutrients but some of them improve production under certain circumstances. Others prevent oxidation of fats (rancidity) in the feed. There is no nutritional deficiency when they are omitted from a ration. When considering the use of a feed additive, the following questions should be asked:

- What are the specific uses of the additive?
- Does the additive have a withdrawal period or a product discard period? Quite often a drug (e.g., antibiotics) will have a required withdrawal period before the birds can be slaughtered or before the eggs can be marketed.
- Can the additive be used in combination with other additives? The FDA has strict regulations as to which additives can be used in combination.
- What is the best form of the product to be used?
- What are the methods of mixing and storing?

Antibiotics, Coccidiostats, and Other Drugs

Antibiotics are produced by living organisms (e.g., molds or bacteria). They are bacteriostatic or bactericidal. Antibiotics at therapeutic levels are effective in reducing the impact of bacterial pathogens and protozoan parasites. Subtherapeutic levels of antibiotics have been widely used in broiler production as growth promotants in a manner as approved by the FDA (US Food and Drug Administration). Some major broiler companies are stopping the use of antibiotics as growth promotants.

History of Antibiotic Use in Poultry

1948: An animal nutritionist and biochemist from Lederle Laboratories (Robert Stokstad and Thomas Jukes, respectively) discovered that antibiotics, initially chlortetracycline, stimulated growth in young chickens.

1950–2016: Antibiotics were widely fed to commercial broiler chickens and turkeys.

2016–2017: Tyson and Perdue Farms announced they were stopping the use of antibiotics in broiler chicken production. Perdue only resorts to the use of antibiotics when chickens are getting sick (about 5 percent of its flocks).

Subtherapeutic levels (5 to 50 g per ton of feed) of antibiotics are included in poultry feeds for their growth-stimulating effects in both broiler chickens and growing turkey. The reasons for the beneficial effects of antibiotics are still not fully understood but is likely related to shifting bacterial populations in the gastrointestinal tract and reduced intestinal thickness due to lack of irritation. Antibiotics can be used to increase egg production, hatchability, and shell quality in poultry. They can also be added to feed at much higher therapeutic concentrations (100 to 400 g per ton of feed) to remedy bacterial infections. The antibiotics most commonly used in poultry rations are bacitracin, virginiamycin, bambermycin, and lincomycin. Other examples of antibiotics used as growth promotants by poultry producers include chlortetracycline; oxytetracycline; penicillin; tylosin; and ionophores, including lasalocid, maduramicin, monensi, narasin, nystatin, salinomycin, and semduramicin.

The status of subtherapeutic levels of antibiotics as growth promoters is, at the present time, somewhat tenuous. There has been pressure from public health advocates and consumer groups to ban the use of antibiotics for poultry and livestock production. In the United States, the FDA has sought for drug companies to voluntarily change their labelling of antibiotics to remove use for production purposes and to shift marketing to require involvement of a veterinarian and prescription for the drug. The reason for the FDA recommendation is a growing concern about antibiotic resistance in bacteria and the need to preserve the effectiveness of antibiotics for human use.

There has been pressure from consumers and groups, such as Consumers Union, for antibiotic-free (ABF) poultry and other livestock products. Increasing numbers of restaurants in the United States are shifting to using only ABF poultry. These include Au Bon Pain, Chick-fil-A, Chipotle, McDonald's, Subway, and Panera Bread. To meet demand for ABF poultry, some companies, such as Foster Farms and Perdue, are producing only ABF chicken. In lieu of antibiotics, the poultry industry is employing other approaches such as prebiotics and probiotics together with phytocompounds/botanics.

Ionophores are an interesting case. They are very effective in reducing the adverse effects of coccidiosis (that is, combatting infection by single-celled parasites belonging to the genus *Eimeria*) but are considered antibiotics. Hence, their use is not allowed in ABF systems of poultry production. This leads to only a limited number of anticoccidian drugs available: amprolium, decoquinate, diclazuril, halofuginone, and nicarbazin. These are used in a rotation along with vaccination to reduce the impact of coccidia. Drugs can be added to the feed to overcome the impact of parasites such as nematode worms and ectoparasites.

Alternatives to Antibiotics in Poultry Production

There can be pathogens, such as *Salmonella* organisms, on particles in poultry feed. Additives like formic acid or sodium formate are being used in feed to reduce pathogens such as *Campylobacter*, *Clostridia*, *E. coli*, and *Salmonella*. Additives to the feed that promote gut health include enzymes (discussed above), probiotics, prebiotics, reduced pH of drinking water with either organic acids or inorganic acids, immunostimulants/modulators, and phytoceuticals (essential oils and saporins). Potential additives include the following bacteriocins, bacteriophages, and immunomodulators (dry fed)—proprietary fermentation yeast + lactobacillus.

Prebiotics and Probiotics

Prebiotics and probiotics are being employed to replace subtherapeutic antibiotics as growth promotants.

Definitions

Prebiotics: Mixtures of microbial nutrients that are added to poultry feed to increase the number of beneficial bacteria and other microorganisms in the intestine and attached to the intestinal wall.

Probiotics: Composed of large numbers of live beneficial microorganisms. The goal of feeding probiotics is to increase the number of beneficial bacteria and other microorganisms in the intestine and attached to the intestinal wall. The goal of increasing beneficial microorganisms is to compete out, and thereby reduce, the numbers of problem (e.g., pathogenic) bacteria in the intestine and/or attached to the intestinal wall.

Phytocompounds/Oils or Botanics

Phytocompounds/oils or botanics are being considered as potential replacements for subtherapeutic antibiotics as growth promotants. There is evidence that growth and/or feed efficiencies, and/or intestinal development of poultry, and/or inhibit growth of pathogens is improved with the following botanics

TEXTBOX 8E

A Deeper Dive: Phytobiotics/Botanics

There is evidence from studies published in refereed journals that botanics can improve poultry growth and/or feed to gain efficiency (see Textbox 8E Table 1).

Textbox 8E Table 1 Effect of a blend of plant oils from basil, caraway, laurel, lemon, oregano, sage, tea, and thyme between days 10–24 in broiler chickens.

	Control	Plant Oils	Pooled SEM[1]
Gain (g)	1012[a]	1080[b]	6
Feed Intake (g)	1533	1507	6
Feed to Gain	1.518[a]	1.402[b]	0.017
Breast Weight (g)	649	678	5.9

[a, b] Different superscript letters indicate different $p < 0.05$

[1]SEM = standard error of the mean.

Data from Khattak et al., 2014.

(plants and/or their oils): chicory (*Cichorium intybus*), cloves (*Eugenia caryophillis*), oregano (*Origanum glandulosum*), peppermint (*Mentha piperita*), and thyme (*Thymus vulgaris*). There is particular interest in the use of thyme and oregano, with these being employed by some major poultry producers.

Enzymes

Enzymes added to poultry feed include (1) phytase, (2) xylanase, (3) glucanase, (4) cellulose, and (5) protease(s). These are covered in more detail below.

Phytase

Phytase uncouples phosphate units from phytate, making phosphate available to be absorbed. Hence, the addition of phytase to feed reduces the amount of phosphate in the feces and also reduces the amount of phosphate needed to be added to the feed. There are multiple phytases:

- 3-phytases (EC 3.1.3.8)
- 4-/6-phytases (EC 3.1.3.26)
- 5-phytases (EC 3.1.3.72)

Cellulase

Cellulose is not broken down by intestinal enzymes in poultry or mammals, however some microorganisms can break down cellulose. These microorganisms produce cellulase.

$$\text{Cellulose} \xrightarrow{\textit{Cellulase}} \text{Disaccharide (glucose} \sim \text{glucose) and glucose}$$

Microorganisms have been bioengineered to produce cellulase that can be incorporated into poultry feed.

Xylanase

Hemicellulose can be broken down by the enzyme xylase to yield xylose. Bacteria have been bioengineered to produce the enzyme zymase. This can be added to the poultry feed to allow breakdown of hemicellulose.

$$\text{Hemicellulose} \xrightarrow{\textit{Xylanase}} \text{Xylose (akin to glucose)}$$

TEXTBOX 8F

A Deeper Dive: Effects of Enzymes on Performance of Broiler Chickens and Digestibility of Dry Matter and Starch

The addition of enzymes can improve the digestibility of various feedstuffs. This is seen in Textboxes 8B with wheat diets and Textbox 8C with rye-based diets. However, there are effects on corn/soybean diets. Textbox 8F Table 1 shows the effect of amylase or amylase together with xylanase on growth, feed efficiency, and apparent ileal digestibility in broiler chickens on a corn/soybean diet.

Addition of both amylase and xylanase improved growth rate and feed efficiency. Moreover, there was increased ileal digestibility of dry matter and apparent ileal digestibility.

Textbox 8F Table 1 Effect of amylase or amylase together with xylanase on growth, feed efficiency and apparent ileal digestibility in broiler chickens on a corn/soybean diet between 14 and 25 days old.

	Body Weight (g)	FCE (%)	Apparent Ileal Digestibility of Dry Matter (%)	Starch Digestibility (%)
Control	1032^{a}	1.109^{a}	62.9^{a}	89.6^{a}
Amylase	1046^{ab}	1.076^{ab}	64.4^{ab}	90.2^{ab}
Amylase + Xylanase	1060^{b}	1.062^{b}	65.6^{b}	92.0^{b}
SEM[1]	4.1	0.008	0.58	0.35

[a,b]Different superscript letter indicates difference $p < 0.05$
[1]SEM= standard error of the mean.

Adapted from Stefanello et al., 2015.

Glucanase

The microorganism enzyme glucanase breaks down β-glucan. Bacteria have been bioengineered to produce glucanase and this is added to poultry feed.

$$\beta\text{-glucan} \xrightarrow{\text{Glucanase}} \text{Glucose}$$

Protease

Addition of proteases to poultry feed improves digestibility of proteins.

$$\text{Proteins} \xrightarrow{\text{Protease}} \text{Amino acids}$$
(plus dipeptides, tripeptides, etc.)

Microorganisms have been bioengineered to produce proteases that can be added to poultry feed.

Antioxidants

All feeds are susceptible to spoilage but those high in fat content are especially prone to autoxidation and consequently rancidity. To prevent this, antioxidants (such as butylated hydroxyanisole, butylated hydroxytoluene, or ethoxyquin) are added to many poultry feeds.

Flavoring Agents

Flavoring agents are feed additives used to increase palatability and feed intake. They are rarely used in poultry production.

8.14 Pelleting and Pellet Binders

Broiler chickens on pelleted feed have a superior performance compared to those on mash. Pellet binders are products that enhance the firmness of pellets. Several feed additives are known to produce a marked increase in the firmness of pellets. These include sodium bentonite (clay); by-products of the wood pulp industry consisting of hemicellulose and lignins; and guar meal, an annual legume produced in Asia. Hemicellulose preparations at levels up to 2.5% may serve as good energy sources, but lignin has no nutritional value. In addition to its binding properties, guar meal provides some protein and energy. Molasses or fat can be added to the feed to aid pelleting, as well as providing a concentrated source of energy.

Textbox 8G

A Deeper Dive: Effects of Feed Type on the Performance of Broiler Chickens

In a study by Amerah and colleagues (2007) comparing pelleted versus mash diets and medium or coarse feed particles, broiler chickens had a markedly superior performance on pelleted feed compared to those on mash (see Textbox 8G Table 1). Particle size had no effect on performance when the feed was incorporated into pellets. However, there was superior performance when fed coarse feed particles in mash. Pelleted feed was associated with shifts in the microanatomy of the small intestine with, for instance, greater villus height and crypt depth (for instance in the duodenum).

Textbox 8G Table 1 Effect of feed type[1] on broiler chickens.

	Mean ± SEM	
Parameter	**Mash**	**Pellets**
Weight gain (g)	453 ± 15	834 ± 15*
Feed intake (g)	777 ± 20	1271 ± 20*
Feed: gain	1.717 ± 0.017	1.525 ± 0.017*
Duodenum		
Villus height (μm)	962 ± 20	1197 ± 24*
Crypt depth (μm)	89 ± 7	100 ± 5
Jejunum		
Villus height (μm)	477 ± 27	676 ± 27*
Crypt depth (μm)	72 ± 7	99 ± 6*

[1]Medium-sized particles fed to day 21.
*Difference $p < 0.001$.

Data from Amerah et al., 2007.

8.15 Feed Additives that Enhance the Color or Quality of Poultry Products

Feeds that contain large amounts of xanthophylls and carotenoids produce a deep yellow color in the beak, skin, and shanks of yellow-skinned breeds of chickens. Table 8.8 summarizes the concentration of

Table 8.8 Concentrations of xanthophyll in various feedstuffs.

Feedstuff	Xanthophyll Content (mg/kg)
Marigold petal meal	7,000
Algae, common, dried	2,000
Alfalfa juice protein, 40% protein	800
Alfalfa meal, 20% protein	240
Corn gluten meal, 41% protein	132
Corn, yellow	20

xanthophylls in various feedstuffs. Some consumers associate this yellow coloring with quality and, in many cases, are willing to pay a premium price for uncooked chicken meat looking yellow. Processors of egg yolks are frequently interested in producing dark-colored yolks to maximize coloration of egg noodles and other food products. In recognition of these consumer preferences, many producers add ingredients containing xanthophylls, such as marigold petals (or the extracted xanthophylls), to finisher broiler chicken feeds.

8.16 Grit

Poultry do not have teeth to grind feed. Instead, most mechanical treatment of ingest (grinding) occurs in the muscular gizzard. The more thoroughly feed is ground, the more surface area is created for digestion and subsequent absorption. Hence, when hard, coarse, or fibrous feeds are fed to poultry, grit is sometimes added to supply additional surface for grinding within the gizzard. When mash or finely ground feeds (or such feed following pelleting) are used, the value of grit is greatly diminished. The shells of oyster, clam, and coquina, along with limestone, can be used for grit for layer feed, also providing a source of calcium.

8.17 Antifungal Additives (Mold Inhibitors)

Antifungals are agents that destroy fungi. Feeds provide an excellent environment for the growth of fungi that are detrimental to the health of poultry, such as *Aspergillus flavus*, *Fusarium*, and *Candida albicans*. *C. albicans* is the causative agent of a condition in poultry called thrush or moniliasis. Moreover, some fungi produce toxins (mycotoxins) that adversely affect poultry. The toxin produced by *Aspergillus flavus* is known as aflatoxin. Growing ducklings, goslings, or turkey poults are markedly more susceptible to aflatoxins than young chickens. Fungi can affect feed intake and subsequent production through contamination at one or more of four stages in the feeding chain: (1) in the field (pre-harvest), (2) during storage, (3) at mixing, and again, (4) during storage.

All feedstuffs should be dried below the critical moisture content (< 12%) that permits the growth of molds. Additionally, mold inhibitors should be added to high-moisture feeds that are exposed to air during storage. Propionic acid, acetic acid, and sodium propionate are used in high-moisture feeds to inhibit mold growth. Feed manufacturers can add such antifungals as copper sulfate to prevent mold growth.

8.18 Evaluating Poultry Feeds

Poultry producers and integrators evaluate the feeds and feedstuffs they use for composition and quality. The following are characteristics of good grains and other concentrates:

- Seeds are not split or cracked.
- Feeds, feedstuffs, and seeds are of low-moisture content—less than 12%.
- Seeds have accepted color.
- Feeds, feedstuffs, and seeds are free from mold.
- Feeds, feedstuffs, and seeds are free from rodent and insect damage.
- Feeds, feedstuffs, and seeds are free from foreign material, such as iron filings.
- Feeds, feedstuffs, and seeds are free from rancid odor.

Chemical Analysis

Chemical analyses have been developed that provide a rough indicator of the value of a feedstuff or ration. Chemical analysis of feeds and feedstuffs includes crude protein, ether extract or crude fat, crude fiber, ash or mineral, and moisture. Such proximate analyses are useful but have drawbacks as the crude protein and the ether extract does not reflect availability. In addition, specific chemical and microbiological determinations can be made from many of the vitamins and individual mineral elements. Feed composition tables serve as a basis for feed formulation. Commercially prepared feeds are required by state law to be labeled with a list of ingredients and a guaranteed analysis.

Bomb Calorimetry

When compounds are burned completely in the presence of oxygen, the resulting heat is referred to as gross energy or the heat of combustion. The bomb calorimeter is used to determine the gross energy of feed.

Biological Analysis

The biological response of the birds (feeding trials) is the ultimate indicator of nutritional quality; such tests are expensive and require time. Chemical analysis is an important adjunct to feed and feedstuff evaluation. Biological tests are important in evaluating protein and energy-yielding nutrients (carbohydrates and fats) such as the following:

1. **Biological measure of protein utilization**. The amount of protein or nitrogen digested by poultry can be determined by a balance experiment. Intake of protein is compared to the measured undigested protein in the feces of the bird. The biological value of a protein source or amino acid is defined as the amount of protein retained in the body expressed as a percentage of the digestible protein available.
2. **Biological measure of energy utilization**. The total energy content of a feed can be measured by completely burning the feed in an apparatus known as a bomb calorimeter. Poultry do not extract all of the energy in feed. Hence, the term **digestible energy** is used to describe the total energy of the feed minus that which remains undigested. **Metabolizable energy** is the total energy in the feed minus both fecal and urinary energy. This represents the available energy for use by the bird. The **net energy** value of a feed is the metabolizable energy content minus the energy employed in utilizing it. Thus, net energy may be used for body storage or the production of heat and muscular activity. Metabolizable energy values are used to describe the energy content of poultry feedstuffs and rations. Metabolizable energy values are relatively easy to measure in poultry where the feces and urine are voided together and are little affected by various physiological conditions.
3. **Cost Factor**. From the standpoint of a poultry producer or integrator, the most important measurement of a feed is net returns. Cost per pound (or kilogram or per ton of feed), and pounds of feed required to produce a pound (or kilogram) of broiler or a dozen eggs are major factors affecting the cost per unit of poultry products produced.

Today, poultry producers/integrators formulate poultry feed at the least cost to provide optimal production. Among the factors to be understood are the following:

1. The nutritional requirements of their birds.
2. Quality and costs of individual feedstuffs and alternatives. Feed prices vary widely. For profitable production, therefore, feeds with similar nutritive properties should be interchanged as price relationships warrant.
3. The long-term availability of feedstocks.
4. The moisture content of the feed ingredients.
5. Transportation costs.
6. The storage capabilities of the feed and feed stocks.
7. Relevant government regulations, especially as to levels, drug combinations, and withdrawals.
8. Impact of feedstuffs on requirements by large purchasers (such as restaurants seeking a vegetarian diet for the poultry) and the export market.

TEXTBOX 8H

Points for Discussion

1. With the advent of genetically modified cereals, should public policy be based on science or special interest groups? How should producers react?
2. What are the differences between using therapeutic and subtherapeutic levels of antibiotics in poultry production?
3. With the decreased use of subtherapeutic levels of antibiotics for poultry production, what evidence should be used by producers to employ supplements such as probiotics, prebiotics, and phytoadditives/botanics?

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9

Poultry Feeding Standards

Diet Formulation and Feeding Programs

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List the factors involved in feed formulation.
2. List the factors affecting nutrient requirements for poultry.
3. Know what is/are the overall goal(s) of feed formulation.
4. Know what the NRC is.
5. Know what the NRC *Nutrient Requirements of Poultry* is and how it is useful.
6. Know how the NRC requirements are developed.
7. Know what a digestible amino acid is and why it is important in feed formulation.
8. Know why it is important to use digestible amino acids in feed formulation.
9. Know why the recommendations for feed components for commercial poultry differ from those of the NRC.
10. Know what happens when a feed is formulated with an ingredient at levels too low (e.g., following the NRC rather than company recommendations).
11. Know what happens when a feed is formulated with an ingredient at levels too high.
12. Know the specific requirements of crude protein, lysine, and methionine for (1) starter-broiler feed, (2) grower-broiler feed, and (3) finisher-broiler feed.
13. Know the requirements for metabolizable energy, crude protein, lysine, methionine, and calcium at different stages of lay for white-egg layer feed.
14. Know the requirements of crude protein, lysine, methionine, and calcium at different stages of lay for (1) brown-egg layer feed, (2) broiler breeder feed, (3) turkey-breeder hen feed, (4) growing-turkey feed, (5) growing-duck feed, and (6) emu or ostrich feed.
15. List reasons for slowing the development of broiler breeders and turkey breeders.
16. List ways to limit feed intake during breeder development.

9.1 Overview

Critical to poultry production is the availability of high quality feed to meet the nutritional needs of the birds. Figure 9.1 shows an example of the systems delivering feed to poultry. There is considerable research-based information available on the nutritional requirements of poultry. This information is limited primarily to chickens and turkeys but some gaps remain in our knowledge. Poultry feeding has changed

Figure 9.1
A system for storing and delivering feed for poultry. (Courtesy USDA NCRS; photograph by Bob Nichols.)

more than the feeding of any other species, outpacing other livestock sectors. Commercial poultry are produced in integrated systems or large companies. This can facilitate rapid employment of new information from recent research. Well-balanced diets containing adequate sources of all known nutrient materials are fed for maximum production. Feed composition is varied with the type of poultry production (e.g., meat type/broiler, turkey and egg laying) and the time in the productive system or prior to production. The daily feed consumption is taken into consideration and the nutrient content of feed (energy, amino acids, vitamins, and minerals) varies so as to compensate for the reduced feed intake and meet requirements.

The feed required to produce a unit of eggs, broilers, and turkeys has declined. The most dramatic change has occurred in broiler chickens, where the feed to gain ratio (feed efficiency) has declined from 4.7 in 1925, to 2.4 in 1965, to 1.95 in 1995, to 1.89 in 2015, to 1.82 in 2018. This chapter details two aspects of poultry feeding: (1) feeding standards and diets, and (2) feeding programs. Poultry producers have the following major alternatives for acquisition of feed:

- Growers of broilers and turkeys receive the complete feed from the integrator and their feed-mixing plant.
- Producer companies (such as egg producers) produce a complete feed at their feed-mixing plant.

Additionally, poultry producers may use the following alternatives for feed:

- Purchase of a commercial complete feed from a feed-mixing plant.
- Purchase of a commercially prepared protein supplement reinforced with vitamins and minerals. This is blended with local or homegrown grain.
- Purchase of a commercially prepared vitamin-mineral premix to be mixed with an oil meal and subsequently blended with local or homegrown grain.
- Purchase of individual ingredients (including vitamins and minerals) and mixing the complete feed.

9.2 Factors Involved in Formulating Poultry Diets

Before formulating a poultry diet intelligently, it is necessary to know the following:

1. Nutrient requirements of the particular birds to be fed, which calls for feeding standards.
2. Availability, nutrient content, and cost of feed ingredients (feedstuffs).
3. Acceptability and physical condition of feedstuffs.
4. Average daily consumption of the birds to be fed.
5. Presence of substances harmful to product quality, such as fungal toxins (mycotoxins such as aflatoxins and fumonisins).

9.3 Nutrient Requirement Determination

The nutritive requirements for a specific substance are determined by finding the **minimum** amount of the nutrient that permits **maximum** development of the productive functions such as growth, feed efficiency, or egg production. For amino acids, the nutrient requirements are increasingly expressed as ileal digestible amino acids. The content of digestible amino acids varies in different feedstuffs. Ileal digestible amino acids in a feedstuff is determined by comparing the level of the specific amino acid in a bolus of feed and the level in the ileum. Markers are used as reference materials to correct to other nutrients, etc.

9.4 Overview of Feeding Standards

Feeding standards are tables listing the amounts of one or more nutrients required by different species of poultry or livestock for growth, development, or production. Feeding standards are expressed in either (1) the quantities of nutrients required per day or (2) the concentration in the diet. The first type is used where animals are either provided a given amount of a feed during a 24-hour period or where the feed needs to be formulated based on feed intake. The second is used where animals are provided a diet without limitation on the time in which it is consumed.

Compositions of feed have been based on those published by the National Research Council (NRC) in 1994, with a revision currently being developed. Periodically, a NRC committee of outstanding researchers is formed. These members have worked extensively with the animal species whose requirements are being reviewed. The committee revises the nutrient requirements of each species for different functions and nutritional needs of each major type of livestock and poultry are addressed separately and in depth. Feeding requirements were last reported for the various types of poultry in 1994. Breeding companies use these standards to make recommendations on feeds tailored to meet the nutrient requirements of their birds. The NRC requirements are conclusions reached over 20 years ago. These conclusions are, therefore, based on research conducted from 24 to over 40 years ago. While still useful, nutrition research has continued since 1994. Moreover, today's poultry are very different from those over a quarter of a century ago due to the tremendous genetic improvement. It is likely that the nutritional requirements for today's poultry differ from those of 1994. Breeding companies produce their own recommendations for nutrient constituents for their birds.

NRC Nutrient Requirements of Poultry

What Is the NRC?

The NRC is the National Research Council (established 1916) in the United States. It is under the three National Academies—The National Academies of Sciences, Engineering, and Medicine. The NRC brings together scientific leaders to come to conclusions based on research. One such endeavor is the NRC *Nutrient Requirements of Poultry*, with the 9th edition published in 1994.

Utility of the NRC Nutrient Requirements of Poultry

The *Nutrient Requirements of Poultry* provides an invaluable compendium of the requirements of nutrients for different poultry species (e.g., chickens, turkeys, and ducks) at different life stages and different genetic backgrounds (broilers, replacement pullets, Leghorn-type white-egg layers and brown-egg layers).

Although feeding standards are necessary guides, cost must also be considered. For example, producers are interested in obtaining a level of egg production that will make the largest net returns in light of current feed costs and the market price of eggs. Moreover, feeding standards tell nothing about the palatability or physical nature of the feed, or management differences, or effects of stress or diseases.

National Research Council (NRC) Requirements for Poultry

The most recent NRC requirements for nutrients differ according to the species (chicken, turkey, duck, or ostrich), type (broiler meat chicken, white-egg layer, or brown-egg layer), and age/stage of growth and development of the bird. A deficiency of a nutrient can be a limiting factor in egg production or growth. NRC standards do not provide for margins of safety; rather, the values reported represent sufficiency. A number of factors may affect the nutritional requirements of poultry, including the following:

- **Temperature and humidity.** When conditions deviate much from temperatures of 60–75°F (15.5–23.9°C) and humidities between 40 and 60%, adjustments in nutrient concentrations are made to compensate for changes in feed intake (discussed in more detail under "Breeder Turkeys").
- **Genetic differences.** Genetic differences among strains affect nutrient requirements. It is strongly

recommended that the manufacturer's recommendations be used for their specific lines.

The nutrient composition of individual feedstuffs is variable. In order to compensate for these conditions, the nutritionist tests the individual major feedstuff for composition and may add a margin of safety to the stated requirements in diet formulation.

9.5 How to Balance Diets

The increasing complexity of poultry diets, along with larger and larger enterprises, makes it imperative that the producers who choose to mix feed be sure that they will have a nutritionally balanced and adequate diet. When fed *ad libitum* (free choice), birds eat to satisfy their energy requirements. Consequently, it is possible to approximate the intake of all nutrients by including them in the feed in specific ratios to available energy. Thus, the energy content of the diet must be considered in formulating to meet a desired intake of all essential nutrients other than energy itself.

Large poultry companies, including integrators and large feed producers, who do their own mixing or formulating rely on the services of a nutritionist(s) to formulate the feeds. Good poultry producers should understand the importance of balanced diets. A reasonably good job can be done in formulating diets by hand but this is laborious and may lead to a feed deficient in specific nutrients and cause production problems. Diet formulation consists of combining feedstuffs in the proper ratio in order to supply the daily nutrient requirements of the bird. This may be accomplished by the methods presented below. In computing poultry diets, more than simple arithmetic should be considered, for no set of figures can fully substitute for experience and observation of the birds. Before attempting to balance a diet, the following points should be considered:

1. **Availability and cost of the different feed ingredients.** The first step in diet formulation is to determine what feeds are available and their cost. Cost of ingredients should be based on delivery after processing.
2. **Moisture content.** When considering costs and balancing diets, feeds should be placed on a comparable moisture basis; usually, either as-fed or moisture-free.
3. **Composition of the feeds under consideration.** Feed composition tables should be considered only as guides. Analysis of major feedstuffs is a very useful adjunct. Whenever possible, it is best to take a representative sample of each major feed ingredient (e.g., corn) and have a chemical analysis made of it for the more common constituents protein, specific essential amino acids, fat, fiber, nitrogen-free extract, and moisture; and often calcium, phosphorus, and carotene.
4. **Quality of the feed ingredient.** Factors include uniformity, storage time, and freedom from contamination. Again, this emphasizes the utility of analysis.

Computer Methods

Poultry and feed companies use computers in diet formulation. Despite their sophistication, the primary advantages are accuracy and speed of computation. In addition, computer software used in diet balancing provides a means of organizing needed information in a logical and systematic manner. The computer should be viewed as an extension of the knowledge and skills of the formulator. Two basic approaches to diet formulation are practiced with computers: (1) trial-and-error formulation and (2) linear programming (LP).

Trial-and-Error Formulation with the Computer

Many software programs allow for trial-and-error diet balancing. Nutritionists at feed mills frequently use this technique to enter diets into the computer given to them by other nutritionists or by a producer. The objective in this case is to confirm the nutrient values for the diet based on the specific ingredients used by the feed manufacturer. In many cases, these diets are not to be altered without permission. In other cases, the number of ingredients for a specific diet may be limited so that the trial-and-error technique is just as fast as using linear programming to arrive at the desired nutrient levels in the diet.

Linear Programming (LP)

The most common technique for computer formulation of diets is the linear programming technique or least-cost diet formulation. Programs are in use that solve for maximization of income over feed costs. Regardless, the poultry nutritionist should always keep in mind that maximizing net profit is the only true objective of diet formulations.

9.6 Feeding Programs

The nutritive requirements of poultry vary according to (1) species, between broiler or egg-laying chickens, turkeys, and ducks, etc.; (2) age; and (3) stage of production. For this reason, many different diets are required. Feeds must meet the nutrient requirements of the birds, as shown in the National Research Council's nutrient requirement tables and breeding company guides. These values meet minimum requirements but do not provide for any margins of safety.

Birds eat primarily to satisfy their energy needs, and the temperature of the environment has an important influence on feed intake. The warmer the environment, the less birds eat, therefore the requirement of all nutrients, expressed as a percentage of the diet, is dependent upon the environmental temperature. Other factors affecting feed intake are health, genetics, form of feed, nutritional balance, stress, body size, and rate of egg production or growth.

9.7 Feeding Broiler Chickens

Broiler feeds differ for different phases of growth and there are specific requirements for the (1) starter, (2) grower, and (3) finisher. In turn, the finisher phase can be subdivided into finisher 1 and finisher 2.

Starter Feeds

Starter feeds meet the needs of early growth, including (1) initial post-hatching skeletal growth and development and (2) muscle growth and development. They have the following features:

- Relatively high concentrations of metabolizable energy (about 3000 kilocalories per kg).
- Relatively high concentrations of protein (21–22% crude protein) and essential amino acids such as lysine (> 1.3%) and methionine (> 0.5%) (see Table 9.1).
- Moderately high levels of macrominerals such as calcium (> 0.9%) (see Table 9.2).

Grower Feeds

Grower feeds meet the needs of growth. They have the following features:

- Higher concentrations of metabolizable energy (about 3100–3200 kilocalories per kg).
- High levels of protein (19–21.5% crude protein) and essential amino acids such as lysine (~1.25%) and methionine (~0.5%) (see Table 9.1).
- Moderate levels of macrominerals such as calcium (~0.9%) (see Table 9.2).

Finisher Feeds

Finisher feeds meet the needs of growth (particularly breast weight) prior to marketing. They have the following characteristics:

- Higher concentrations of metabolizable energy (about 3100–3200 kilocalories per kg).
- High levels of protein (19–21.5% crude protein) and essential amino acids such as lysine (~1.25%) and methionine (~0.5%) (see Table 9.3).
- Moderate levels of macrominerals such as calcium (~0.9%) (see Table 9.4).

Table 9.1 Comparison of NRC requirements for energy, protein, and specific essential amino acids for starter and grower broiler-chicken feeds with company recommendations for Cobb 500 and Ross 308s/708s.

	NRC	Cobb 500 (Starter[1])	Ross 308 or 708 (Starter[1])	Cobb 500 (Grower[1])	Ross 308 or 708 (Grower[1])
Duration in Days	0–21	0–10	0–10	11–22	11–24
ME Kcal/kg (MJ/kg)	3200 (13.39)	3008 (12.59)	3000 (12.55)	3086 (12.91)	3100 (12.97)
Protein	23	21–22	23	19–20	21.5
Lysine	1.10	1.32	1.44	1.19	1.29
Methionine	0.50	0.50	0.56	0.48	0.51
Methionine and Cysteine	0.90	0.98	1.08	0.89	0.99
Tryptophan	0.20	0.20	0.23	0.19	0.21
Threonine	0.80	0.86	0.97	0.78	0.88
Arginine	1.25	1.38	1.52	1.25	1.37
Valine	0.90	1.00	1.10	0.91	1.00
Isoleucine	0.80	0.88	0.97	0.80	0.89

[1] Starter feeds are crumb while grower feeds are pellets.

Table 9.2 Comparison of NRC requirements for macrominerals for starter and grower broiler-chicken feeds with company recommendations for Cobb 500 and Ross 308s/708s.

	NRC	Cobb 500 (Starter)	Ross 308 or 708 (Starter)	Cobb 500 (Grower)	Ross 308 or 708 (Grower)
Duration in Days	0–21	0–10	0–10	11–22	11–24
Calcium %	1.00	0.90	0.96	0.90	0.87
Available Phosphorus %	0.45	0.45	0.48	0.45	0.435
Sodium %	0.20	0.16–0.23	0.16–0.23	0.16–0.23	0.16–0.23
Chloride %	0.20	0.17–0.35	0.16–0.23	0.17–0.35	0.16–0.23
Potassium %	0.30	0.60–0.95	0.40–1.00	0.60–0.95	0.40–0.90
Choline g/kg	1.3	N/A[1]	1.7	N/A[1]	1.7 {1.6}[2]
Linoleic Acid %	1.0	1.0	1.0 {1.25}[2]	1.0	1.0 {1.20}[2]

[1] N/A: Data not available.
[2] Recommended level in Ross 708 when different from Ross 308.

Table 9.3 Comparison of NRC requirements for energy, protein, and specific essential amino acids for finisher diets with company recommendations for Cobb 500 and Ross 308s/708s.

	NRC		Cobb 500 (Finisher)	Ross 308 or 708 (Finisher)
Duration in Days	22–42	43–56	23–42	25–Market
ME Kcal/kg (MJ/kg)	3200 (13.39)	3200 (13.39)	3167 (13.25)	3200 (13.39)
Protein	20	18	18-19	20
Lysine	1.00	0.85	1.05	1.19
Methionine	0.38	0.32	0.43	0.48
Methionine and Cysteine	0.72	0.60	0.82	0.94
Tryptophan	0.18	0.16	0.19	0.19
Threonine	0.74	0.68	0.71	0.81
Arginine	1.10	1.00	1.13	1.26
Valine	0.82	0.70	0.81	0.93
Isoleucine	0.73	0.62	0.71	0.83

Table 9.4 Comparison of NRC requirements for macrominerals for finisher diets with company recommendations for Cobb 500 and Ross 308s/708s.

	NRC		Cobb 500 (Finisher)	Ross 308 or 708 (Finisher)
Duration in Days	22–42	43–56	23–42	25–Market
Calcium %	0.90	0.80	0.76	0.81
Available Phosphorus %	0.35	0.30	0.38	0.405
Sodium %	0.15	0.12	0.15–0.23	0.16–0.20
Chloride %	0.15	0.12	0.15–0.25	0.16–0.23
Potassium %	0.30	0.30	0.60–0.80	0.40–0.90
Choline g/kg	1.0	0.75	N/A	1.55
Linoleic Acid %	1.0	1.0	1.0	1.0

TEXTBOX 9A

A Deeper Dive: Comparison of Industry and NRC Requirements for Broiler Chickens

Compared to the NRC requirements, commercial broiler chickens require the following: During starter and growing phases, less energy [ME↓], more lysine [Lys↑], less calcium [Ca↓], more choline [choline↑], and more potassium [K↑]. During the finishing phase, more methionine [Met↑], more threonine [Thr↑], more arginine [Arg↑], less calcium [Ca↓], more choline [choline↑], and more potassium [K↑].

Textbox 9A Table 1 Recommendations for digestible amino acids in starter diets for commercial broiler chicks.

	Cobb 500	Ross 308 or 708
Digestible Lysine	1.18	1.28
Digestible Methionine	0.45	0.51
Digestible Methionine and Cysteine	0.88	0.95
Digestible Tryptophan	0.18	0.20
Digestible Threonine	0.77	0.86
Digestible Arginine	1.24	1.37
Digestible Valine	0.89	0.96
Digestible Isoleucine	0.79	0.86

9.8 FEEDING WHITE-EGG LAYERS

Overall Considerations of Feeding Laying Hens

The following additional information is pertinent to feeding layers:

1. The greatest component of the cost of producing eggs is feed.
2. Requirements for specific feed compositions and nutrient intakes for laying hens is either expressed as mg per day or as a percentage of the diet (Table 9.5).
3. Laying hens have small body size, low basal metabolic rates, low feed intakes, and are prolific layers (see Table 9.6. for feed consumption).
4. Feed consumption per bird varies primarily with egg production and genetically determined body size (see Table 9.6).
5. Feed consumption is also affected by disease and environmental factors such as temperature.
6. Feeding is generally ad libitum during the laying period (see Table 9.6 for feed consumption).
7. The objective of feeding laying hens is to produce a dozen eggs of good quality and size at the lowest possible feed cost. Thus, the actual cost of the feed that a layer eats in producing a dozen eggs determines the economics of formulating the feed.
8. Feed can affect egg quality.
   - Deficiencies of calcium, phosphorus, manganese, and vitamin D_3 lead to poor shell quality.
   - Yolk color is almost entirely dependent on the bird's diet.
   - Low vitamin A levels may increase the incidence of blood spots.

Table 9.5 Recommended feed compositions and nutrient intakes in white- and brown-egg layers based on NRC requirements.

	Feed composition as %		Feed Intake as mg per Day	
	Leghorn Type[1]	Brown-Egg Layers[2]	Leghorn Type	Brown-Egg Layers
Protein	15	15	15,000	16,500
Lysine	0.69	0.69	690	760
Methionine	0.30	0.30	300	330
Methionine and Cysteine	0.58	0.58	580	645
Tryptophan	0.16	0.16	160	175
Threonine	0.47	0.47	470	520
Arginine	0.70	0.70	700	770
Valine	0.70	0.70	700	770
Isoleucine	0.65	0.66	650	715

[1] Assumes 100 gram per day feed intake.
[2] Assumes 110 gram per day feed intake with consequent increase in nutrient requirement.

Feeding White-Egg Layers

The nutritional requirements for Leghorn-like white-egg layers are now conventionally divided into phases, such as the five phases for Hy-Line W-36 white-egg layers:

- Layer 1: from first egg to egg production peaking to 2% decline
- Layer 2: from a 2% decline in egg production to 90% lay
- Layer 3: from 85–89% lay

Table 9.6 Feed intake figures that could be employed in feed formulation.[1]

	Leghorn Type g per Day	Brown-Egg Layers g per Day
NRC	100	110
First Egg to Peaking to 2% Decline	84	103
Layer Phase 2: 2% Decline to 89% lay	—	110
Layer Phase 2: 2% Decline to 90% lay	96	—
Layer Phase 3: 85–89% lay	100	110
Layer Phase 4: 80–85%	94	—
Layer Phase 4: < 85%	—	109
Layer Phase 5: < 80%	93	—

[1] Note: Differences in phases between white- (Leghorn-type) and brown-egg layers.

- Layer 4: 80–85% lay
- Layer 5: < 80% lay

Hy-Line W-36 white-egg layers require relatively high levels of protein and specific amino acids to meet the needs of the eggs. As egg lay decreases, these requirements decline (see Table 9.7). Table 9.8 shows the requirements for some macrominerals. The requirement for calcium is high and is even higher later in egg lay. It is recommended that the ratio of fine to coarse particles supplying calcium increasingly shift to coarse particles as the lay proceeds (see Table 9.9).

9.9 Feeding Brown-Egg Layers

The requirements for protein and specific amino acids in brown-egg layers are summarized in Table 9.10. In addition, the requirements of digestible amino acids are shown. As the laying cycle progresses, the requirements for both crude protein and specific amino acids decline. Where the requirement for an individual amino acid is not addressed from combinations of cereals (maize) and protein sources such as legumes (soybeans), then synthetic amino acids or analogues are incorporated into feed.

There is a very high dietary requirement for calcium in the feed of brown-egg layers (see Table 9.11).

Table 9.7 Comparison of NRC recommendations for protein and specific amino acid intake[1](mg per day) with company recommendations for Hy-Line W-36 white-egg layers.

	Recommendations for Protein and Amino Acids as mg per Day					
	NRC	Hy-Line				
Nutrient	**Leghorn type**	**First egg to peaking to 2% decline**	**Layer 2: 2% decline to 90% lay**	**Layer 3: 85–89% lay**	**Layer 4: 80–85%**	**Layer 5: < 80%**
ME kilocal/kg	2900	2844–2955	2844–2944	2822–2922	2800–2844	2778–2822
Crude Protein	15,000	16,000	15,500	15,250	15,000	14,750
Lysine	690	881 (805)	821 (750)	777 (710)	761 (695)	745 (680)
Methionine	300	424 (394)	395 (368)	374 (348)	359 (334)	351 (326)
Methionine and Cysteine	580	763 (676)	711 (630)	673 (596)	643 (570)	629 (558)
Tryptophan	160	202 (169)	188 (158)	178 (149)	174 (146)	171 (143)
Threonine	470	663 (564)	618 (525)	585 (497)	572 (487)	560 (476)
Arginine	700	900 (837)	839 (780)	794 (738)	777 (723)	760 (707)
Valine	700	781 (708)	728 (660)	689 (625)	675 (612)	660 (598)
Isoleucine	650	675 (628)	629 (585)	595 (554)	583 (542)	570 (530)

[1] Recommendations on digestible amino acid (standardized ileal digestibility) are shown in parentheses.

Data from Hy-Line and NRC.

Table 9.8 Comparison of NRC recommendations for mineral intake with company recommendations for Hy-Line W36 white-egg layers.

	NRC	Hy-Line W-36				
	Leghorn Type (mg per day)	First Egg to Peaking to 2% Decline	Layer 2 2% Decline to 90% lay	Layer 3 85–89% Lay	Layer 4 80–85%	Layer 5 < 80%
Calcium mg per Day	3250	4150	4300	4400	4600	4650
Available Phosphorus mg per Day	250	485	470	550	400	380
Sodium mg per Day	150	180	180	180	180	180
Chloride mg per Day	160	180	180	180	180	180
Choline mg per Day	105	100	100	100	100	100
Linoleic Acid mg per Day	1000	1000	1000	1000	1000	1000

Data from Hy-Line.

Table 9.9 Recommended calcium particle ratio in Hy-Line W-36 white egg layers.

	Fine: Coarse
First Egg to Peaking to 2% Decline	50: 50
Layer 2: 2% Decline to 90% Lay	45: 55
Layer 3: 85–89% Lay	40: 60
Layer 4: 80–85%	35: 65
Layer 5: < 80%	35: 65

Data from Hy-Line.

Company recommendations are markedly higher than the NRC requirements. This reflects genetic improvements in egg production. This calcium is deposited predominantly into the shell of the developing egg. Breeding companies recommend that the concentrations of calcium in the feed need to be increased as the laying proceeds into phases 2 to 3 to 4 (see Table 9.11). Along with the increases in calcium, there should be changes in the form of the calcium. The proportion of fine to coarse particles should change with more coarse particles needed later in the lay cycle (see Table 9.12).

The requirement for available phosphate is moderate (see Table 9.11). This is to assure that there is sufficient phosphate for (1) bone maintenance (formation and resorption) and (2) the needs of the egg with phosphate used to produce the yolk precursor phosphoproteins and phospholipids.

9.10 Feeding Replacement Pullets

Meeting the nutritional requirements of pullets is important to subsequent production as layers. Leghorn-type pullets are seldom restricted-fed during the growing period as lighting can be used to control feed consumption and sexual development. Recommended nutrient requirements are shown in Table 9.13.

Important information to feeding replacement pullets include the following (see Table 9.3):

- Feed accounts for approximately 60% of the cost of raising replacement pullets.
- Use complete starter feeds for chicks until 6 weeks of age. These feeds are high in protein and specific essential amino acids.
- When the chicks are 6 weeks old, change from the starter to a grower feed with lower protein and amino acid requirements.
- When the pullets are 12 weeks old, shift to a finisher diet with still lower protein and amino acid.
- When the pullets are 18 weeks old, shift to a pre-lay feed with increased calcium levels.

9.11 Feeding Broiler Breeder Hens

The requirements for metabolizable energy, protein, amino acids, and macrominerals are summarized in Table 9.14. For maintenance and egg production, broiler breeder hens have high requirements for energy, protein, specific amino acids (such as arginine, isoleucine, lysine,

TEXTBOX 9B

A Deeper Dive: Comparison of Industry and NRC Requirements for Slow Growth CobbSasso 150s™

Compared to the NRC requirements, slow growth CobbSasso 150™ chickens require the following: More lysine [Lys↑], more methionine [Met↑], more threonine [Thr↑], more arginine [Arg↑], more available phosphate [P↑], and more linoleic acid [linoleic acid↑].

Textbox 9B Table 1 Comparison of the goal body weights for slow growth CobbSasso 150™ chickens in certified programs with commercial broiler weights from 1994 as reported in the NRC.

Age (Days)	CobbSasso 150™		NRC 1994	
	Male	Female	Male	Female
28	0.87	0.82	1.08	0.96
42	1.75	1.48	2.09	1.74
56	2.49	2.02	3.07	2.51
70	3.09	2.62	N/A	N/A

Textbox 9B Table 2 Comparison of the nutritional requirements of slow growth CobbSasso 150™ chickens in certified programs with commercial broiler weights.[1]

	NRC	CobbSasso 150™ Starter	NRC	CobbSasso 150™ Grower	NRC	CobbSasso 150™ Finisher
Duration in Days	0–21	0–28	22–42	29–49	43–56	> 50
ME Kcal/kg (MJ/kg)	3200 (13.39)	3000 (12.55)	3200 (13.39)	3140 (13.14)	3200 (13.39)	3180 (13.31)
Protein	23	22	20	19	18	18
Lysine	1.10	1.35 (1.22)	1.00	1.20 (1.08)	0.85	1.11 (1.00)
Methionine	0.50	0.52 (0.46)	0.38	0.48 (0.43)	0.32	0.45 (0.41)
Methionine and Cysteine	0.90	1.04 (0.90)	0.72	0.91 (0.82)	0.60	0.86 0.77()
Tryptophan	0.20	0.23	0.18	0.20	0.16	0.20
Threonine	0.80	0.90	0.74	0.80	0.68	0.77
Arginine	1.25	1.42	1.10	1.27	1.00	1.20
Calcium %	1.00	0.95	0.90	0.85	0.80	0.80
Available Phosphorus %	0.45	0.48	0.35	0.43	0.30	0.40
Sodium %	0.20	0.17	0.15	0.16	0.12	0.16
Chloride %	0.20	0.16	0.15	0.15	0.12	0.15
Linoleic Acid	1.0	1.25	1.0	1.20	1.0	1.00

[1] As reported by the NRC in 1994.

Table 9.10 Comparison of NRC recommendations for protein and specific amino acid intake[1] (mg per day) with company recommendations for Hy-Line brown-egg layers.

	Recommendations for Protein and Amino Acids as mg per Day				
	NRC	Hy-Line			
Nutrient		First Egg to Peaking to 2% Decline	Layer 2: 2% Decline to 89% Lay	Layer 3: 85–89% Lay	Layer 4: < 85%
Crude Protein	16,500	17,000	16,750	16,000	15,500
Lysine	760	909 (830)	876 (800)	854 (780)	821 (750)
Methionine	330	437 (407)	422 (392)	411 (382)	387 (360)
Methionine and Cysteine	645	805 (714)	776 (688)	748 (663)	711 (630)
Tryptophan	175	208 (174)	201 (168)	196 (164)	188 (158)
Threonine	520	648 (581)	659 (560)	642 (546)	618 (525)
Arginine	770	928 (863)	895 (832)	872 (811)	839 (780)
Valine	770	806 (730)	776 (704)	757 (686)	728 (660)
Isoleucine	715	696 (647)	671 (624)	654 (608)	629 (585)

[1] Recommendations on digestible amino acid are shown in parentheses.

Data from Hy-Line and NRC.

Table 9.11 Comparison of NRC recommendations for mineral intake with company recommendations for Hy-Line brown-egg layers.

	NRC	Hy-Line Brown-Egg Layers			
	Brown Egg Layers—mg per Day	First egg to peaking to 2% decline	Layer 2 2% decline to 89% lay	Layer 3 85–89% lay	Layer 4 < 85%
Calcium (mg per Day)	3600	4200	4300	4500	4800
Available Phosphorus (mg per Day)	275	460	420	380	360
Sodium (mg per Day)	165	180	180	180	180
Chloride (mg per Day)	145	180	180	180	180
Choline (mg per Day)	115	100	100	100	100
Linoleic Acid (mg per Day)	1100	1000	1000	1000	1000

Data from Hy-Line.

Table 9.12 Recommended calcium particle ratio in Hy-Line brown-egg layers.

	Fine: Coarse
First Egg to Peaking to 2% Decline	50: 50
Layer 2: 2% Decline to 90% Lay	40: 60
Layer 3: 85–89% Lay	35: 65
Layer 4: < 85%	35: 65

Data from Hy-Line.

TEXTBOX 9C

A Deeper Dive: Comparison of Industry and NRC Requirements for Brown-Egg Layers

Compared to the NRC requirements, Hy-Line brown-egg layers require the following: Multiple phases of feeding during the laying cycle, more lysine [Lys↑], more methionine [Met↑], more threonine [Thr↑], and more arginine [Arg↑].

Table 9.13 Comparison of NRC recommendations with company recommendations for Hy-Line Leghorn white-egg layer pullets.

Nutrient as %	NRC	Hy-Line W36*	NRC	Hy-Line W36	NRC	Hy-Line W36	NRC	Hy-Line W36
Age (weeks)	**0–6**		**6–12**		**12–18**		**18 to lay**	
Crude Protein	18	20/18.25	16	17.5	15	16	17	16.5
Lysine	0.85	1.15/1.07	0.60	0.96	0.45	0.83	0.52	0.85
Methionine	0.30	0.51/0.47	0.25	0.44	0.20	0.38	0.22	0.41
Methionine and Cysteine	0.62	0.83	0.52	0.75	0.42	0.67	0.47	0.74
Tryptophan	0.17	0.21	0.14	0.20	0.11	0.18	0.12	0.20
Threonine	0.68	0.82/0.77	0.57	0.70	0.37	0.62	0.47	0.64
Arginine	1.00	1.21/1.13	0.83	1.01	0.67	0.87	0.75	0.90
Valine	0.62	0.83/0.80	0.52	0.70	0.41	0.67	0.46	0.73
Isoleucine	0.60	0.79/0.76	0.50	0.70	0.40	0.61	0.45	0.67
Linoleic acid	1.00	1.0	1.00	1.0	1.00	1.0	1.00	1.0
Calcium	0.90	1.0	0.80	1.0	0.80	1.0–1.4	2.00	2.5
Available phosphate	0.40	0.50	0.35	0.47	0.30	0.45	0.32	0.48
Sodium	0.15	0.18	0.15	0.18	0.15	0.18	0.15	0.18
Chloride	0.15	0.18	0.12	0.18	0.12	0.18	0.12	0.18

*First value 0–3 weeks old and second 3–6 weeks.

Data from Hy-Line and NRC.

Table 9.14 Nutrient requirement of broiler breeder hens.

Nutrient	NRC Kilocal per Day or mg per Day	Ross 308* kilocals per kg or % Breeder 1: 5% Production to 245 Days	Breeder 2: 245–350 Days	Breeder 3: > 350 Days
ME	400–450	2800	2800	2800
Crude Protein	19,500	15	14	13
Lysine	765	0.67	0.62	0.58
Methionine	450	0.41	0.40	0.36
Methionine and Cysteine	700	0.67	0.65	0.83
Tryptophan	190	0.16	0.15	0.14
Threonine	720	0.55	0.53	0.51
Arginine	1,110	0.88	0.86	0.80
Valine	750	0.63	0.60	0.57
Isoleucine	1250	0.56	0.54	0.51
Calcium	4000	3.0	3.2	3.4
Available phosphate[1]	350	0.35	0.33	0.32
Sodium	150	0.18–0.23	0.18–0.23	0.18–0.23
Chloride	185	0.18–0.23	0.18–0.23	0.18–0.23

[1] Non-phytate phosphate.
*Intake ~150 grams per day.

TEXTBOX 9D

A Deeper Dive: Comparison of Industry and NRC Requirements for White-Egg Layer Pullets

Compared to the NRC requirements, commercial turkey hens require the following: Initially more protein [CP↑], more lysine [Lys↑], more methionine [Met↑], more threonine [Thr↑], more arginine [Arg↑], more calcium [Ca↑], and more chloride [Cl↑].

and methionine), calcium, and available (nonphytate) phosphate. The micronutrient nutritional requirements for breeding flocks are also rigorous with high amounts of the following needed: vitamins A, D, E, and B_1, riboflavin, pantothenic acid, niacin, and manganese. Diets with these added ingredients in the right proportions give high hatchability and good development of chicks. Such diets cost more than normal layer diets.

Feeding Growing Broiler Breeders

Heavy broiler breeder pullets accumulate excessive amounts of body fat. To reduce this, feed intake is restricted during later growth and development. This is beneficial because it produces healthier birds and reduces feed costs during the rearing period. The methods commonly employed are the following:

1. **Skip-a-day method**. This involves feeding pullet broiler breeders on alternate days only, from about 9 weeks to sexual maturity. When fed every other day, pullets consume more feed on the days that feed is available than they would normally consume on a daily basis. They are unable, however, to consume enough feed in 1 day to satisfy their total energy requirements for 2 days. Thus, growth and body fat content are reduced.
2. **Daily restriction of feed**. Under this system, the producer determines the amount of feed that is being consumed by the pullets each day and then provides 75 to 85% of the amount of feed that would be consumed on a free-choice basis.
3. **Bulky, low-energy, or low-protein and/or amino acid imbalanced diets**. Another form of restriction involves either the feeding of bulky, low-energy feeds or the feeding of low-protein and/or amino acid imbalanced diets on a free-choice basis between 12 to 20 weeks of age. Under such a program it is possible to restrict the growth of broiler breeder pullets by 10 to 15%; this being comparable to the growth depression with the skip-a-day and daily restriction methods.

9.12 FEEDING TURKEYS

Feeding turkeys involves two distinct areas: (1) feeding market turkeys and (2) feeding turkey breeders.

Feeding Market Turkeys

Ideally, turkeys are provided with multiple different feeds during their growth. For instance, different turkey feeds are to meet the needs of starter and early growth phase of turkeys. Tables 9.15 and 9.16 show the requirements of young and growing turkeys based on NRC requirements and company specifications for commercial turkeys. Nutritional adjustments can be made for high or low ambient temperatures to ensure that the birds consume the necessary amounts of protein, minerals, and vitamins regardless of feed consumption.

Feeding Turkey Breeders

The feeding programs for breeder stock are divided into (1) pre-breeding or holding and (2) breeding (hens). In pre-breeding or holding diets, breeders are fed from about 16 weeks of age, the time they are selected. Holding diets are formulated for medium energy levels. Toms may be fed a nutritionally balanced holding diet from the time of breeder selection throughout the breeding season. Limited feed intake can be used to limit body weights of toms.

Hens are fed the holding diet until the time of light stimulation at about 30 weeks of age. Subsequently, breeders are fed a specific diet (see Table 9.17). Turkey breeder hens must receive an adequate intake of minerals and vitamins both during the holding and laying periods. Calcium is the most important macromineral. As environmental temperature increases, feed intake decreases and nutrient levels in feeds need to be more concentrated (Table 9.17).

Overall Conclusions

The following information is important to feeding turkeys:

1. Prevent poult "starve out." Upon arrival, poults must be encouraged to consume feed and water as soon as possible.
2. Turkeys grow faster than chickens and require metabolizable energy and crude protein.
3. Young turkeys use feed efficiently.

TEXTBOX 9E

A Deeper Dive: Differences in Modern Feeds for Young Turkeys and NRC Requirements

Compared to the NRC requirements, young turkeys require the following based on commercial recommendations (see Table 9.14): more phases, higher metabolizable energy [ME↑], less crude protein [CP↓], more arginine [Arg↑], more linoleic acid [linoleic acid↑], and more calcium [Ca↑].

TEXTBOX 9F

A Deeper Dive: Differences in Modern Feeds for Turkey Breeding Hens and NRC Requirements

Compared to the NRC requirements, commercial turkey hens require the following (see Table 9.17): Lower metabolizable energy [ME↓], more crude protein [CP↑], more lysine [Lys↑], more methionine [Met↑], more threonine [Thr↑], more arginine [Arg↑], more linoleic acid [linoleic acid↑], more calcium [Ca↑], more sodium [Na↑], and more chloride [Cl↑].

4. Turkeys fed for market are fed diets different from those fed for future breeders.
5. Feeding according to age/phase is cost effective.
6. Separate rearing of male and female facilitates feeding to the different requirements of each sex (see Tables 9.15 and 9.16).
7. When a holding diet is used, the hens should be switched to the breeder diet two weeks prior to egg production.
8. Turkeys on pasture consume natural vegetation. This reduces feed costs. However, there are increased risks of infectious diseases and losses from predators.

9.13 Feeding Ducks

Commercial ducks can be grown rapidly and efficiently for meat. Typically, ducks are provided with two feeds sequentially during the growing period (see Table 9.18). A 22% protein starter diet is fed during the first two weeks, followed by a grower-finisher diet containing 16% protein. When feeding ducks, the following are important: (1) growth, (2) feed conversion, (3) proper feather development, and (4) limited carcass fat deposition. There are marked changes in the

Table 9.15 Comparison of NRC requirements and present recommendations for commercial turkeys during starter and early growth.

	NRC	Aviagen	NRC	Aviagen	Aviagen
	0–4 Weeks "Starter"		4–8 Weeks	4–6 Weeks	6–9 Week Males 6–8 Week Females
ME kcal per kg (MJ/kg)	2800	3020	2900	3100	3150
Crude Protein	28	26–28	26	24–26	23–25
Lysine	1.6	1.82	1.5	1.62	1.47
Methionine	0.55	0.65	0.45	0.59	0.54
Methionine and Cysteine	1.05	1.18	0.95	1.07	0.99
Tryptophan	0.26	0.26	0.24	0.26	0.24
Threonine	1.0	1.06	0.95	0.96	0.88
Arginine	1.6	1.86	1.4	1.67	1.51
Valine	1.2	1.22	1.1	1.10	1.01
Isoleucine	1.1	1.11	1.0	0.99	0.91
Linoleic Acid	1.0	1.25	1.0	1.20	1.10
Calcium	1.2	1.49	1.0	1.38	1.24
Available Phosphate	0.6	0.73	0.5	0.68	0.63
Sodium	0.17	0.17	0.17	0.17	0.16
Chloride	0.15	0.20	0.15	0.20	0.19

Table 9.16 Comparison of NRC requirements and present recommendations for commercial turkeys during later growth.

	NRC	Aviagen	NRC	Aviagen	Aviagen	Aviagen
	8–12 weeks	10–12 wk Males 9–10 wk Females	12–16 wks	13–14 wk Male 11–12 wk Female	15–16 wk Male 13–14 wk Female	17–18 wk Male 15–16 wk Female
ME kcal per kg (MJ/kg)	3000	3250	3100	3300	3350	3450
Crude Protein	22	20–22	19	18–20	16–18	14–16
Lysine	1.3	1.31	1.0	1.17	1.09	1.01
Methionine	0.4	0.49	0.35	0.45	0.42	0.41
Methionine and Cysteine	0.8	0.90	0.65	0.82	0.76	0.75
Tryptophan	0.2	0.26	0.18	0.21	0.20	0.20
Threonine	0.8	0.80	0.75	0.73	0.67	0.62
Arginine	1.1	1.35	0.9	1.21	1.12	1.05
Valine	0.9	0.92	0.8	0.83	0.77	0.73
Isoleucine	0.8	0.81	0.6	0.74	0.69	0.65
Linoleic Acid	0.8	1.00	0.8	1.0	0.9	0.9
Calcium	0.85	1.14	0.75	1.00	1.01	0.93
Available Phosphate	0.42	0.58	0.38	0.50	0.51	0.46
Sodium	0.12	0.16	0.12	0.15	0.15	0.15
Chloride	0.14	0.19	0.14	0.18	0.18	0.18

Table 9.17 Comparison of NRC requirements and present recommendations for commercial turkey breeding hens raised under different environmental temperatures.

	NRC	Aviagen		
		Cool 44.6–69.8°F	Moderate 69.9–89.6°F	Hot > 89.6°F
ME kcal per kg	2900	2800	2820	2865
Crude Protein	14	15.5–16.5	17–18	18–20
Lysine	0.6	0.78	0.83	0.88
Methionine	0.2	0.37	0.40	0.45
Methionine and Cysteine	0.4	0.62	0.66	0.70
Tryptophan	0.13	0.16	0.17	0.18
Threonine	0.45	0.57	0.59	0.61
Arginine	0.6	0.85	0.86	0.88
Linoleic Acid	1.1	1.50	1.55	1.55
Calcium	2.25	2.80	2.85	2.90
Available Phosphate	0.35	0.35	0.38	0.40
Sodium	0.12	0.17	0.18	0.20
Chloride	0.12	0.20	0.21	0.22

Table 9.18 Nutrient requirements of ducks.[1]

	Ducks		
	0–2 Weeks	2–7 Weeks	Breeding
ME kcal kg	2900	3000	2900
Crude Protein CP %	22	16	15
Lysine %	0.90	0.65	0.60
Methionine %	0.40	0.30	0.27
Arginine %	1.1	1.0	N/A
Calcium %	0.65	0.60	2.75
Sodium %	0.15	0.15	0.15
Available Phosphate %	0.40	0.30	N/A

[1] N/A information not available

Based on NRC, 1994.

feed for breeding ducks with, for instance, a large increase in calcium requirements.

The following information is pertinent to feeding ducks:

1. Ducks should be fed pellets. For example, 1/8-inch (3.2 mm) pellets can be used for starter diets and 3/16-inch (4.8 mm) pellets for older ducks. Pellets reduce the amount feed required to produce a market duck.
2. Ducks are very susceptible to aflatoxicosis, so it is important to monitor feeds for aflatoxin contamination.
3. If a holding diet is used, it is designed to maintain breeding ducks from about 8 weeks of age until 4 weeks from the beginning of breeding.
4. Ducks on pasture are good foragers, as are geese.

9.14 Feeding Other Avian Species

The NRC's *Nutrient Requirements of Poultry* includes geese, Japanese quail, Bobwhite quail, and Ring-necked pheasants. Recommendations for nutrient requirements for emus and ostriches are provided in Table 9.19.

Table 9.19 Nutrient requirements of ostriches and emus.

	0–9 Weeks	9–42 Weeks	42 Weeks–Market
ME kcal kg	2465	2450	2300
Crude Protein CP %	22	19	16
Lysine %	0.90	0.85	0.75
Methionine + Cystine %	0.70	0.68	0.60
Calcium %	1.5	1.2	1.2
Available Phosphate %	0.75	0.60	0.66

Modified from Scheideley and Sell, 1997.

References and Further Reading

NRC (National Research Council). 1994. *Nutrient Requirements of Poultry.* National Academy Science, Washington, DC.

Scheideley, S. E., and J. L. Sell. 1997. Nutrition Guidelines for Ostriches and Emus. Iowa State University Extension publication Pm-1696.

10

Poultry Management

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Understand the importance of management (managers and staff) to successful poultry production.
2. Know what to consider when launching a poultry enterprise.
3. Know what a business plan should include.
4. Discuss the reasons why a poultry operation should be located in some places and not others.
5. Know what to consider when siting a new poultry unit.
6. Understand the relationship between size of operation and costs.
7. List the characteristics of a successful poultry professional.
8. Understand what a job description, organization chart, and standard operating procedures are.
9. Know why training of all personnel is important.
10. Understand the importance of improving efficiency.
11. Know the major costs in broiler, layer, and turkey operations.
12. Know what the value of regular inspections is.
13. Understand what to look for during inspections.
14. Understand why light is important to poultry production.
15. Discuss savings in utility costs.

10.1 INTRODUCTION

This chapter considers (1) the overall poultry enterprise, (2) important aspects of poultry management and staffing, (3) traits of a poultry professional, (4) approaches to improve the efficiency of the operation, and (5) troubleshooting—the whys and wherefores.

10.2 THE POULTRY ENTERPRISE

When launching or expanding a new poultry enterprise, the owner should do the following:

1. Develop a business plan.
   a. Choice the species.
   b. Consider whether to pursue conventional or specialty production (e.g., organic or pasture-raised).
   c. Determine the sources and costs of inputs such as birds, feed, medication, labor, and utilities.
   d. Determine the market for the product.
   e. Decide on the size of the enterprise including the size and number of poultry houses, costs of construction, and equipment purchases.
   f. Determine the projected revenue, costs (including repaying any loans on the buildings and land, plus depreciation on the buildings and equipment), and profits or losses under a series of eventualities (contingency planning).
2. Consider the site for the operation.
3. Determine where/how the manure or spent litter will be disposed of.
4. Assure that the planned unit is biosecure.

Location

There are two aspects of the determination of the site for production; these being macro and micrositing.

Macrositing of a Poultry Enterprise

It is essential to site a poultry enterprise in a country, region, or state where profits are maximized. To achieve this, it will be important to determine the costs (together with availability) of feed, labor, land, building construction, borrowing money, and any required permits. In addition, there may be considerable costs for adhering to laws and regulations. Another question is whether there are processing facilities, transportation linkages, and markets for the poultry products. Local economic development incentives may shift the cost basis. We can dismiss the assumption that costs and markets are similar in different countries (see Chapter 1) or US states (see Chapter 3), as there are marked differences in production. Moreover, decision makers should be aware that some US states do not allow common ownership of livestock and processing.

Micrositing of a Poultry Enterprise

It is important to site poultry units consistent with local regulations, in a manner that the facility is biosecure and the quality of watershed(s) are not impaired.

Size

Some poultry operations are less profitable than they should be because they are the wrong size; being either too small or too large. Economic studies have shown that net return is in direct proportion to the size of the flock. This is due to economies of scale. Of course, in a bad year the bigger the flock, the greater the potential losses; also, it should be recognized that the bigger and the more complicated the operation, the more competent the management required. Although it is easier to achieve efficiency of equipment, labor, purchases, and marketing in big operations, size per se will not make for greater efficiency; management is still the key to success.

10.3 Management and the Poultry Professional

Five major ingredients are essential to success in the poultry business: (1) high quality management, staff, and where appropriate, growers and management systems; (2) high quality chicks; (3) high quality feed; (4) bird health, bird welfare, and biosecurity; and (5) good records/data. Quality of staff, supervisors, growers, technical representatives, and managers can make or break any poultry enterprise. The importance of these together with having effective training programs cannot be overestimated.

Traits of a Good Poultry Professional

There are established bases for evaluating many articles of trade. They are graded according to well-defined standards and may be chemically analyzed. But no such standard or system of evaluation has evolved for professionals in poultry enterprises. Textbox 10A provides a checklist of traits of effective poultry professionals.

This checklist may be helpful to students as guidance for preparing themselves for being poultry professionals, to employers when selecting or evaluating staff, and to poultry professionals for self-improvement purposes. No attempt has been made to assign a percentage score to each trait. Rather, it is hoped that this checklist will serve as a useful guide for the traits of good poultry professionals. A good poultry professional is an investment, not a cost, and will make money for the producer and integrator.

Job Description, Organization Chart, and Standard Operating Procedures

It is important that all workers know who they report to (plus who their supervisor reports to) and what they are responsible for. There should be clear organization charts and job descriptions. There is a strong case that each operation should be described in standard operating procedures (SOPs). In addition, there must be regular checks on the poultry in all poultry houses (discussed below). Oversight is critical to ensure tasks are being performed in a satisfactory manner. Moreover, there needs to be regular evaluation of employees. Among the most important overall responsibilities are bird performance; bird welfare; sanitation; heating, cooling and ventilation systems; and biosecurity.

Training

All personnel working with poultry should be trained for all the techniques that they will be expected to perform. Moreover, personnel should demonstrate proficiency. Training programs should be held on a regular basis. However, it should be recognized that some workers may have limited ability in the English language.

Incentives

The poultry industry relies on a recruited or hired labor force together with contract growers. Good employees—the kind that everyone wants—are hard to come by and keep. The agricultural labor situation may become more difficult in the years ahead. There is need, therefore, for the industry to succeed in helping to recruit and hold on to top-flight employees while also cutting costs and boosting profits.

Incentive pay and/or profit sharing may be the answer. Many manufacturers have long had an incentive basis. Executives are frequently accorded stock option privileges through which they prosper as the business prospers. Blue-collar workers may be paid on piecework (number of units or pounds produced) or receive bonuses based on quotas. Also, workers get overtime pay and have group insurance and a retirement plan. A few industries have a true profit-sharing arrangement based on net profit where a specified percentage is divided among employees. No two systems are alike, yet each is designed to pay more for labor as long as it improves production and efficiency. In this way, both owners and workers benefit from better performance.

The incentive basis chosen should be tailored to fit the specific operation and overall company policy, with consideration given to the kind and size of operation, present and projected productivity levels, mechanization, and other factors. Family-owned and family-operated poultry farms can have a built-in incentive basis; there is pride of ownership, and all members of the family are fully cognizant that they prosper as the business prospers.

TEXTBOX 10A

Required Traits of Poultry Professionals

- **Integrity:** Honesty, reliability, dependability, self-awareness, sincerity, loyalty, courage (to make difficult decisions), and resilience.
- **Communication:** Written and oral proficiency (one-on-one, in small groups, and in large groups) together with the ability to speak different languages and display cultural sensitivity.
- **Knowledge and Skills:** Exhibits technical poultry knowledge, business acumen, and computer literacy. Is aware of the latest information about the poultry industry, such as in *Poultry International*, the *Poultry Site*, and *Feedstuffs*, and the national and international economic outlook (e.g., *The Wall Street Journal*, *Financial Times*, and *The Economist*).
- **Ability to Work in Teams and with Other Employees:** Practices team-building skills and demonstrates empathy, a sense of humor, cooperation, balance, and being task-orientated.
- **Drive:** Enthusiasm, initiative, a willingness to get their hands dirty, and has a "today not tomorrow" mentality.
- **Leadership Capability:** Identifies opportunities and potential challenges, prioritizes challenges, brings the best out of subordinates and colleagues, delegates effectively (avoids the extremes of micromanagement or being totally hands off), gives credit where it is warranted, and ensures subordinates work in an ethical manner. "A good manager does the job right, a leader does the right job" (paraphrasing Warren Bennis: "Managers do things right. Leaders do the right thing").
- **Problem-Solving and Analyzing:** Analyzes the situation (is data- and knowledge-driven), considers both pros and cons of potential solutions, thinks outside the box, is results-orientated, and stays ahead of the curve.
- **Planner and Organizer:** Sets goals; insures that job descriptions, standard operating procedures (SOP), and organization charts are in place/up to date; understands SWOT analysis (strengths, weaknesses, opportunities, and threats) and strategic planning for a company, unit, division, facilities or farm; and ensures that a biosecurity plan and communications plan (in the event of public relations problems) are in place and reviewed on a regular basis.
- **Personality:** Confident, cheerful, cooperative, optimistic (even in adverse situations), and always willing to learn.
- **Professionalism:** Seen as a professional in all actions (including on social media) and has clothing appropriate for the situation (see Textbox 10A Figure 1).

Textbox 10A Figure 1 Poultry professional in broiler facility. (Source: branislavpudar/Shutterstock)

Indirect Incentives

Normally we think of incentives as monetary in nature. However, there are other ways of encouraging employees to do a better job. These are indirect incentives and include, in addition to good wages or salaries, the following: good working conditions and labor relations, vacation time with pay, time off and sick leave, maternity leave, group health insurance, and opportunities for continuing education/training and promotion.

How Much Incentive to Pay?

After reaching a decision to pay incentives, it is necessary to arrive at how much to pay. The following are some guidelines that may be helpful:

- What is the industry or company standard?
- Pay the going base or guaranteed salary, then add the incentive pay above this.
- Determine the total stipend (the base salary plus incentive) to which you are willing to go.
- Before making any offers, always check the plan on paper to see how it would have worked out in past years based on your records and how it will work out as you achieve the future projected production.

10.4 Improving Efficiency

There are two ways to increase profits in any business: (1) increase returns, and/or (2) cut costs. It might be thought that an individual poultry producer or poultry company can do little to increase returns because supply and demand determines prices. However, an integrator can increase the diversity of poultry food products and thereby increase consumer demand. For a grower, there are incentive programs reflecting live body weight at slaughter, mortalities, and breast muscle yield. Moreover, a producer (and frequently a grower) can cut costs. Cutting on items that account for the largest percentage of cost of production offers the greatest possibility to lower costs. For example, cutting feed costs is extremely important because it accounts for up to 75% of total costs.

Major Production Costs of Layers

The items of highest cost for shell egg production are feed, pullets, housing/equipment (e.g., caging) (interest and depreciation), labor, and utilities. These account for 96% of the cost of producing eggs, with feed being 55 to 75%. Hen replacement costs (raising replacement pullets) are ranked in order: feed, chicks, and labor, with feed being twice the cost of the chicks.

Major Production Costs of Broilers and Turkeys

The major broiler production costs are feed, chicks, housing/equipment, labor, and utilities. Feed accounts for about 70% of the total cost of production. The chief turkey production costs are feed, poults, fixed costs (land, buildings, equipment, maintenance, taxes, and insurance), labor, and utilities (see Figure 10.1). Before adding expensive equipment, owners or managers should determine if it will pay. They should compare the cost of mechanization with its savings in labor. The break-even point on how much you can afford to invest in equipment to replace employees can be arrived at by the following formula:

- Equation 1: Annual savings in labor from new equipment = Amount you can afford to invest in the new equipment divided by a factor based on the depreciation on the equipment together with operating and service costs. If we assume a 5-year depreciation then the factor is 0.2. Alternatively the factor may be 0.15–0.20 or even 0.25 depending on a financial advisor's or accountant's recommendations and any tax consequences. Example: If hired labor costs $30,000 per year (including health insurance, social security, etc.), this becomes Equation 2.
- Equation 2: $30,000 / the factor, say 0.2 = $150,000. This is the break-even point. As labor costs are going up, it may be good business to exceed this limitation under some circumstances. Nevertheless, the break-even point ($150,000 in this case) is probably the

Figure 10.1 Turkey poults being raised on deep litter with feeder and waterer lines. (Courtesy of the Iowa Turkey Federation)

maximum expenditure that can be economically justified at the time.

10.5 Inspecting Poultry Units, Birds, and Troubleshooting

Each poultry house needs regular inspection. Poultry professionals should know the signs for properly functioning equipment and bird well-being. The poultry professionals should be able to recognize trouble once it strikes, diagnose the cause, and institute corrective measures, thereby holding mortality and economic losses to a minimum. This means that they must know what to look for when troubleshooting. Poultry units need to be checked for the following:

- The heating, cooling, and ventilation systems should operate such that birds are at, or close to, temperatures optimal to the species and age. In addition, the ventilation system is operating to ensure high quality of both the air and flooring.
- Sightings and/or signs of rodents and other pests.
- Are all aspects of the biosecurity plan (see Chapter 16) in place?
- Has equipment and house been sanitized correctly?
- What is the condition of the litter?

It is important to observe the behavior of the birds to ensure that they do not have compromised health or welfare. Examples of compromised welfare include injuries and mortalities. Behaviors to watch for include huddling (they are likely to be too cold or whether there is a draft), panting (they are likely to be too hot), a pattern of chicks or poults around the heater for brooding chicks (see Chapter 16), struggling to reach the feeders and drinkers, lameness, and any abnormal behaviors.

It is recommended that both poultry units and the birds be inspected a minimum of twice daily. It is important that there be good communication among the caretakers and the poultry professional(s). A method to accomplish this is a paper record in the poultry house. Workers and/or poultry professionals record their visits to the house (date, time, and name or initials) and any problems (including mortality, culling, injured birds, equipment disrepair, water intake, whether the height of the feeders and drinkers have to be adjusted, etc.) and observations noted during their visit (such as abnormal behaviors). This system could be coupled with an electronic record system. Poultry health is covered in detail in Chapter 11.

Communication System and Fencing around Units

Business visitors to poultry farms are not interested in seeing the birds; they are there to talk to the manager or owner. To prevent the spread of poultry diseases, only those who need to come into the unit should be allowed to enter. This necessitates fencing and locked gates, as well as a communication system, so that potential visitors can be screened. Necessary sanitary precautions must be taken first to assure biosecurity (see Chapter 11).

The requirements for a workable system are fences, a locked gate(s), a communication device, and/or a sign at the gate telling visitors how to reach the person they want to see (cell phone number). Five different types of communication systems can be employed:

1. **Horns, buzzers, or bells** that are activated by a push button at the gate. Of all devices, these are the simplest and least costly. However, someone must go to the gate in order to see who is there.
2. **Two-way speaker system** ("squawk box"). It may consist of a multiple set, with units in various buildings and a central unit in the office. This arrangement is versatile. It can be set up so that managers can screen visitors without leaving their work.
3. **Belt-mounted beeper**. This device may signal the wearer to the phone, to the office, or to the front gate.
4. **Two-way radio or cell phone** that is hand-carried or vehicle-mounted.
5. **Combination communication device and gate lock deactivator**. Visitors can let the manager or office personnel know they are at the entrance. The gate lock can then be deactivated from the office or other location on the ranch.

The producer should decide what system best suits the particular operation. The important thing is to have an effective communication system as a prerequisite of poultry disease prevention. In addition to installing a communication device, the owner or manager should establish a certain time during the day to be in the office to receive telephone calls or use the cell phone. Salespeople should visit only by appointment and business should be conducted in the office or by telephone.

Management of Light

It has long been known that light stimulates egg production in chickens and other birds. Records show that the ancient Chinese made their canaries sing more by placing a lighted candle by the cage at night. In the early 1900s, poultry producers in the State of

Washington increased winter egg production by placing a lighted lantern in the chicken house for a few hours each evening. Light acts in a physiological manner. For instance, light influences reproduction (acting on photoreceptors in the eyes and in the brain) by activating the hypothalamus to stimulate the pituitary gland to release luteinizing hormone (LH) and follicle stimulating hormone (FSH). These in turn cause the development of the reproductive system, ultimately leading to ovulation. Because of this phenomenon, the management of lighting systems is an integral part of modern poultry production.

Lighting systems have been designed, differing primarily in windowless versus open houses, in light-to-dark ratio and in continuous versus intermittent light. It is noteworthy that chickens do not respond to all wavelengths of light. Orange and red lights are most effective in stimulating reproduction, while shorter wavelengths (e.g., blue light) are not effective. Normal white incandescent bulbs or approved light-emitting diodes (LEDs, discussed below) give sufficient light at effective wavelengths. It is also noteworthy that light stimulus seems to have a threshold level of intensity beyond which further increases in brightness of light have no effect. A light intensity of 0.5 to 1.0 foot-candle (5–10 lux) should be provided at the darkest points of exposure of the hens. Excessive light is both unnecessary and uneconomical. Automatic time switches should be installed in poultry houses for pullets or layers.

Definitions

Light intensity can be measured as lux (lx) in the SI system or foot-candles (fc) in US customary units (Society of Automotive Engineers or SAE units).

Foot-candle: One **lumen (lm)** of illuminance per square foot and is equal to 10.74 lux in the SI system.

Lux (lx): The metric analogues to foot-candles measuring the luminous flux per unit area. One lux is equal to one lumen per square meter.

Energy Conservation—Save Energy, Save Costs

The price of utilities (electricity and gas) vary with world markets. Irrespective of the price, utilities are a cost to the poultry industry. It is important, therefore, that poultry producers practice energy conservation to lower overall production costs.

Light-Emitting Diodes (LEDs)

The poultry industry is increasingly replacing incandescent light bulbs with light-emitting diodes (LEDs). This can reduce costs of electricity by between 80 and 85%. The cost of LEDs is markedly higher than incandescent light bulbs. Thus, it is important to calculate the savings over the life of the LED. For growers, it is important to verify that the integrator allows use of LEDs and what is permitted in terms of brands and the color/wavelength of light being emitted. The LEDs should have been demonstrated to withstand the rigor of the environment of the poultry house, such as dust and humidity. As the biology of poultry (e.g., growth and reproduction) is sensitive to the intensity of light, it is important that the LEDs used can be dimmed and that the correct light intensity is produced when the LEDs are dimmed. Some producers consider that a switch from compact fluorescent lights to LEDs seems to increase calmness in broiler chickens.

Other Energy Saving Measures

Some estimate that the poultry industry could save 20% of the energy used. This is a matter of attention to details and modification of existing practices. Little expense, if any, is needed to institute energy-saving methods. Some ways in which to save energy follow.

- **Brooding and growing**. Brooding uses the most energy of any phase of poultry production. Costs can be reduced by (1) partial house brooding, (2) clustering three or four brooders together and encircling the cluster with a single solid chick guard, (3) keeping the recommended number of chicks under each hover (under-capacity increases fuel cost per bird), and (4) adjusting brooding temperatures to conserve heat.
- **Housing**. Good management of existing housing, along with modifying it if necessary (e.g., adding insulation), saves energy. Regularly checking and sealing air leaks around doors, air intakes, and fans will reduce heat loss (during the winter). Adding insulation to existing houses is expensive. But if the current insulation is inadequate, it will likely be cheaper to buy and install more insulation than to buy feed or fuel. Always make sure that wall and ceiling insulation has the recommended R-value.
- **Ventilation**. Energy can be saved by a well-managed ventilation system. One way is to reduce ventilation rates (during the winter). Temperature within

the house can be allowed to rise to levels acceptable depending on poultry species, provided air quality is kept acceptable and if ammonia does not exceed 50 ppm (discussed in more detail in Chapter 11). This saves electricity and reduces feed usage too. Energy can also be saved by the selection of only the most efficient fans and keeping fans clean.

- **Feeding, watering, and management**. The energy requirements for watering and feeding are relatively small. Nevertheless, some savings can be effected in most operations. The number of times automatic feeders run each day should be reduced to the minimum needed for the desired level of feed consumption; 3 to 4 runs a day may suffice. Energy is conserved by keeping the watering system in good repair to prevent leakage and spilling. Also, consideration should be given to switching from continuous-flow troughs to a valve-controlled or discontinuous system to reduce pumping in the water used. If continuous-flow troughs are used, turn the water off at night and operate the system on an intermittent schedule in the daytime.

Among the management programs that may be instituted to save energy are keeping all moving equipment in good repair, cleaning manure-removal equipment after each use, and using only the recommended size of motors on feeders, waterers, egg-collection equipment, and other automation, as well as maintaining and adjusting such equipment regularly.

REFERENCES AND FURTHER READING

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Animal Waste and Other Impacts of Poultry on the Environment

11

CHAPTER SECTIONS

11.1 Introduction
11.2 Environmental Stewardship
11.3 Poultry Waste (Excreta)
11.4 Disposal of Mortalities
11.5 Agriculture and Global Warming
11.6 Poultry, Nitrogen, and Water Quality
11.7 Poultry, Phosphate, and Water Quality
11.8 Other Impacts of Poultry on Water
11.9 Relationships with Neighbors and Communities
11.10 Other Issues

OBJECTIVES

After studying this chapter, you should be able to:

1. Understand the issues related to poultry waste.
2. List the major regulations affecting poultry waste.
3. Explain how spent litter or layer excreta (manure) is disposed of.
4. Explain the advantages and disadvantages of each system.
5. Understand the phosphorus cycle.
6. Understand what happens to nitrogen in poultry waste.
7. Know what the nitrogen cycle is.
8. Explain what happens to ammonia emissions from poultry.
9. List the ways spent litter can be disposed of and the advantages and disadvantages.
10. Know the methods for the disposal of mortalities.
11. Give the major reasons for using various methods of disposal of mortalities.
12. Know what global warming is.
13. Know what a greenhouse gas (GHG) is.
14. Explain the global impact of agriculture on greenhouse gas emissions
15. List the nuisances from poultry production.

For students in the United States:

16. What is an AFO?
17. What is a CAFO?
18. On what basis does the US EPA regulate agriculture?

11.1 INTRODUCTION

Poultry and poultry processing produce considerable amounts of waste, including excreta and other waste (see Table 11.1). Poultry producers have long recognized the need to dispose of this in a responsible, environmentally sound manner using the resources in the waste profitably.

11.2 ENVIRONMENTAL STEWARDSHIP

Environmental stewardship includes the following:

- **Water footprint**: This is an indicator of the use of freshwater, including both the volumes used (together with the volume extracted as a percentage of the freshwater available as a scarcity index) and the polluted wastewater (amount and quality of effluent). The pollutants relevant to the poultry industry are water pH, biological oxygen demand (BOD), total nitrogen, total phosphate, total suspended solids, and oil and grease.

TEXTBOX 11A

Regulation of Poultry Production in the United States

The Clean Water Act

The Federal Water Pollution Control Act of 1948 addressed water pollution. This was amended by the US Congress in 1972 and the resulting legislation became the Clean Water Act. The goal of the Clean Water Act is to ensure the chemical, physical, and biological integrity of US waterways (see Textbox 11A Figure 1).

The Clean Water Act included the provision that it is "unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions." The United States Environmental Protection Agency (US EPA) is charged with enforcing the Clean Water Act. The US EPA regulates critical aspects of poultry and livestock production under the Clean Water Act.

AFOs and CAFOs

The US EPA refers to farms where animals are raised in confinement for at least 45 days as "Animal Feeding Operations (AFOs)" and "Concentrated Animal Feeding Operations (CAFOs). The EPA regulates CAFOs as "point sources" of pollution including nitrogen, phosphate, organic materials, pathogens, hormones, and antibiotics in excreta; this being in a confined area. Although the EPA defined a CAFO as having more than one thousand animal units (equal to 125,000 broiler chickens or 82,000 layers or pullets), there are three classes of CAFO (see Textbox 11A Table 1): small, medium, and large. The size thresholds for each are summarized in Textbox 11A Table 1.

In addition, not only does a small animal operation have to have the number of animals that fall into the EPA's scheme to be designated as a CAFO, it must also be deemed as a "significant source of pollutants." Moreover, to be designated as a medium CAFO, the operation has to meet one of the following criteria related to discharge:

1. A man-made ditch or pipe that can carry either manure or wastewater to surface waters.
2. Animals coming directly into contact with surface water.

Textbox 11A Figure 1 Water quality in the South Fork of the Holston River (one of the ten heritage rivers in the US). Federal agencies and cooperating farmers developed and implemented a comprehensive program of wetlands and other buffers, fencing, rotational grazing, and tree planting. (Source: USDA NCRS; photograph by Jeff Vanuga)

The second criterion is unlikely to apply to poultry production but may become important if there are increases in pasture-produced poultry. Operators of CAFOs are required to have National Pollutant Discharge Elimination System (NPDES) permits. These are usually issued by individual US states, except for Idaho, Massachusetts, New Hampshire, and New Mexico, where the US EPA issues permits. The permitting requires nutrient management plans.

Textbook 11A Table 1 Size thresholds (number of animals) for designation of types of CAFO.

	Small CAFO	Medium CAFO	Large CAFO
Broilers (Liquid Manure Handling)	< 9000	9,000–29,999	30,000 and greater
Broilers (Nonliquid Manure Handling)	< 37,500	37,500–124,999	125,000 and greater
Layers (Liquid Manure Handling)	< 9000	9,000–29,999	30,000 and greater
Layers (Nonliquid Manure Handling)	< 25,000	25,000–81,999	82,000 and greater
Turkeys	< 16,500	16,500 - 54,999	50,000 and greater
Ducks (Liquid Manure Handling)	< 1500	1,500–4,999	5000 and greater
Ducks (Nonliquid Manure Handling)	< 10,000	10,000–29,999	30,000 and greater

Data from US EPA.

- **Air quality**: This includes emission of **greenhouse gases (GHG)**, particulates, sulfur oxide (contributing to air rain), carbon dioxide, ammonia, and volatile carbon compounds (from frying).
- Energy usage, conservation, and renewable energy usage.
- Worker safety.
- Community sustainability.
- **Low numbers of violations**: Notices of Violations (NOVs) and permit exceedances (situations when permitted levels exceed those permitted).

An environmental sustainability index is built on addressing the above. Companies such as Tyson Foods regularly announce their performance relative to sustainability standards.

11.3 Poultry Waste (Excreta)

Whether real or perceived, there is little doubt that the public, the media, and policy makers will continue to have concerns about pollution from animal waste and manure. However, government regulations about animal waste need to be followed with concern for concomitant costs. Manure should be looked upon as a resource and a cost. Therefore, planned animal waste management is an important part of modern poultry management. The collection, transport, storage, and use of spent litter/manure must meet sanitary and pollution control regulations. Modern poultry buildings and equipment are designed to allow ease of handling the excreta in a safe and efficient manner.

Table 11.1 summarizes the amount of manure produced by poultry and livestock. In poultry, the excreta is a mix of the semisolid urine together with feces. There are substantial amounts of plant nutrients including nitrogen and phosphate. Initially the nitrogen is predominantly in the form of uric acid but transforms to ammonia due to microbial action. In poultry, the phosphate is in the form of both organic and inorganic phosphate. The organic phosphate is gradually converted to inorganic phosphate by microbial action.

Table 11.1 Excreta production in poultry compared to other livestock species (in either lb per day per 1000 lb animal unit or kg per day per 1000 kg animal unit).

	Total	Nitrogen	Phosphorus
Broiler Chickens	80.4	1.19	0.34
Laying Hens	60.5	0.83	0.31
Turkeys	43.6	0.74	0.28
Beef Cattle	59.1	0.31	0.11
Dairy Cattle	80.0	0.45	0.07
Pigs	63.1	0.42	0.16

Based on USDA Natural Resources Conservation Service.

Laying hens in conventional cages have their excreta collected in a relatively dry form. In contrast, cage-free systems can have litter and hence spent litter. Broiler chicks and turkey poults are raised in litter; when this is removed it is most commonly land-applied, providing nitrogen, potassium, and phosphorus for growing crops. It is estimated that broiler chickens produced about 45 million tons of poultry excreta (manure) in spent litter in 2014. This has the following plant nutrients:

- 2.4 million tons of nitrogen.
- 1.5 million tons of potassium.
- 0.7 million tons of phosphorus.

Poultry excreta can be land-applied as a replacement source of fertilizer for crop production. The predominant way of disposing of poultry excreta is by land application.

Figure 11.1 Composted turkey litter. (Courtesy USDA NCRS; photograph by Jeff Vanuga)

Precautions when Using Layer Waste or Spent Litter (Poultry Manure) as a Fertilizer

The following precautions should be observed when using manure as a fertilizer:

- Apply at rates that the plants can utilize.
- Avoid applying waste closer than 100 feet (30.5 meters) to waterways, streams, lakes, wells, springs, or ponds.
- Do not apply where percolation of water down through the soil is not good, or where irrigation water is very salty or inadequate to move salts downward.
- Composting litter (see Figure 11.1) reduces losses into surface water.
- Do not spread on frozen ground.
- Distribute the waste as uniformly as possible on the area to be covered.
- Incorporate, preferably by injecting (or possibly plowing or discing), manure into the soil as quickly as possible after application. This will maximize nutrient conservation, reduce odors, and minimize runoff pollution.
- Minimize odor problems by the following:
  - —Adopt a "good-neighbor" policy. Discuss with neighbors about the timing of manure application, avoiding times when neighbors have family gatherings, weddings, or outdoor activities planned.
  - —Inject manure into the soil.
  - —Spread only on days when the wind is not blowing toward neighbors or populated areas.
  - —In irrigated areas, (a) irrigate thoroughly to leach excess salts below the root zone, and (b) allow about a month after irrigation before planting to enable soil microorganisms to begin decomposition of manure.

Storage of Spent Litter and Caked Litter

Spent or caked litter should not to be stored close to the poultry house(s) to reduce the risk of spreading diseases between flocks and for rodent and insect control. Moreover, used litter should not be land applied in close proximity (within 2 miles) of the poultry houses it came from. This is for biosecurity. Spent litter can also be utilized for electricity and/or heat generation by incineration (directly or following gasification or palletization) and composting followed by land application. Burning manure is allowed in the European Union if done at 850ºC so that pathogens are destroyed and odor is greatly reduced. The heat can be used to heat poultry houses, with natural gas as a backup. Biogas is produced by the anaerobic digestion of spent litter, poultry excreta, or livestock manure and contains about 60% methane. The economics of this are presently unfavorable unless there are tax incentives.

11.4 Disposal of Mortalities

There is always a need to dispose of mortalities irrespective of whether these are routine mortalities, culled birds, or catastrophic mortalities as a result of disease or depopulation. It is critically important to

Textbox 11B

A Deeper Dive: Disposal of Spent Litter

Issues with Spent Litter

Litter is frequently used for multiple flocks of birds. Caked litter is removed and replaced by fresh litter. Spent litter contains elevated concentrations of minerals such as copper, manganese, and zinc. Up to 2011, spent litter contained arsenic from the coccidiostat roxarsone (3-nitro-4-hydroxyphenylarsonic acid). Poultry waste is a source of microorganisms containing viruses, bacteria, fungi, and single-celled parasites. There are high levels of microbes (about 10^{10} cells per g) in poultry litter. Poultry manure can contain the antibiotics that are used as antibiotic growth promotants. If land applied, there are risks of the antibiotics migrating through the groundwater to waterways. Spent litter can also be a site for the growth of maggots. These develop into flies that risk spreading diseases among the poultry. In addition, the flies can impact neighbors. This is the basis for the requirement that spent litter should be stored at least 3.2 km (2 miles) from poultry houses (see below).

How Spent Litter and/or Caked Litter Should Be Treated

Litter disposal must follow all appropriate federal, state, county, and local rules and regulations. The goals of these rules are to protect public health and the environment. The following methods may be permitted.

1. It can be land applied and plowed/knifed-in within 7 days onto arable crop land. The used litter has a real value as plant nutrients—nitrogen, phosphate, and potassium.
2. After "composting" for at least a month, it can be land applied to areas used for livestock grazing. Again, the used litter has a significant value as it contains nitrogen, phosphate, and potassium.
3. There is also some return to the grower/producer if the exhausted litter is used as a biofuel.
4. There is no return and frequently a cost when the spent litter is buried in an approved landfill, quarry, or hole, or simply incinerated, generating heat and/or electricity.

The choice of method of disposal should balance profitability (revenue – costs) and environmental stewardship. Biosecurity should never be compromised. Caked litter may be removed by a specialist contractor.

Textbox 11C

A Deeper Dive: Environmental Stewardship and Layers in the US

There have been marked improvements in environmental stewardship in layer production. These are summarized in Textbox 11C Table 1. It is evident that there is less energy needed to produce eggs, less discharges into water that could lead to eutrophication, lower acidifying discharges, and reduced emission of greenhouse gases between 1960 and 2010. These improvements are the result of increased efficiency of production coupled with vigorous environmental stewardship.

Animal Waste as Plant Nutrients

Xin and colleagues (2011) concluded that "proper application of laying hen manure to crops (corn and soybean) improves water quality and crop yields, as compared with use of commercial fertilizers."

Animal Waste and Free-Range Poultry

Animal waste is deposited on to the land with free-range poultry production (Xin et al., 2011). Pasture rotation is important due to the addition of both nitrogen and phosphorus and the potential for run-off (Xin et al., 2011).

Textbox 11C Table 1 Changes in release of phosphate and acidic emissions from the laying industry.

	1960	2010
Cumulative Energy Usage (MJ MT^{-1} Eggs)	18	12
Greenhouse Gas Emissions		
Pullets (MT of CO_2-equi. per 1000 Pullets)	13.5	5.4
Layers (MT of CO_2-equi. t^{-1} Eggs)	7.2	2.1
Discharges into Water that Could Lead to Eutrophication		
Pullets (kg of PO_4-equi. per 1000 Pullets	129	54
Layers (kg of PO_4-equi. t-1 Eggs)	70	20
Acidifying Emissions		
Pullets (kg of SO_2-equi. per 1000 Pullets)	390	196
Layers (kg of SO_2-equi. t-1 Eggs)	200	70

Pelletier et al., 2014.

follow all federal and state laws and regulations. Methods to dispose of mortalities include (1) burial; (2) composting with a carbon source (straw, sawdust, wood chips, chopped corn stalks, peat) followed by land application of the compost mixed with manure as plant nutrients; (3) rendering followed by on-farm storage in freezers; (4) incineration; and (5) landfills.

Burial in Pits

To preclude seepage of nitrogen, phosphate, pathogens, etc., into groundwater, the following arrangements are recommended. Burial sites must be at least 300 feet (91 meters) from the nearest stream, well(s), or pond(s). The bottom of the burial site should be at least two feet (0.6 meters) above the seasonal-high water table and, if relevant, one foot (0.3 meters) above floodplain level. Mortalities should be covered with a minimum of 2.5 feet (0.76 meters) of topsoil. Usually burial should be on site and requires permitting. There can be issues with seepage depending on soil type and in the event of disturbance of the land (e.g., with earthquakes). In the event of depopulation mortalities, there is a need for emergency permits. A temporary alternative to pits for catastrophic mortalities is above-ground storage with the mortalities covered with soil. Under these circumstances, the mortalities will need to be transported to a permanent site as the crisis abates.

Composting

Mortalities can be decomposed by controlled biological decomposition by bacterial action to generate a stable, humus-like product (see Figure 11.2). The advantages of composting include a low cost, consistency with biosecurity, and environmental stewardship. The composting process requires (1) a balance of carbon (bulking agent) to nitrogen (about 25:1); (2) moisture at about 50%; (3) enough porosity to allow carbon dioxide and other gases generated by decomposition; (4) a temperature in the range of 135° to 145°F as heat is generated (such that most pathogens are destroyed); (5) and a pH of 6.5 to 7.2 (with pH above 8.0 odor becomes a problem).

Composting is recommended in many US states and there may be a cost share. However, in other states it may be restricted and require a permit. If done correctly the process is not associated with odor, fleas, or vermin. However, there is generation of carbon dioxide and other greenhouse gases. The following are a

A. Drum composting.

B. Product of composting mortalities.

Figure 11.2 Composting is an effective manner of disposing of poultry mortalities. (Photos courtesy of River Bend Molding, Inc. Manufacturer of Ecodrum™ composter) set of guidelines for composting: (1) animals should be composted within 24 hours of death; (2) carcasses should be fully degraded before removal or land application; (3) runoff water should be avoided (e.g., by covering); (4) composting should not occur close to waterways or wells; (5) and composting should be done in a weather-resistant structure.

Incineration

Mortalities from depopulations can be addressed using mobile incinerators that reach temperatures of 1,800 to 2,200°F (982–1204°C). This is needed to ensure destruction of pathogens and a general absence of emission of odor. These can consume five tons of carcasses per hour together with fuel (wood or burnable waste).

Landfills

Municipal solid waste landfills must have impermeable liners overlaying 2 feet of clay soil along the bottom and sides of the landfill. Disadvantages of this approach include cost (tipping fees) and the limits placed for the manager of the landfill.

Transportation to Disposal Sites

Transportation to a disposal site must be performed in a manner consistent with the biosecurity plan to prevent the spread of pathogens to other poultry or wild birds. In the event of catastrophic mortalities due to highly pathogenic diseases such as avian influenza, the USDA or its state partners act to ensure the safe transport of carcasses. There can be a need for movement outside the quarantine zone and this requires specific permits.

11.5 Agriculture and Global Warming

There is very strong evidence that human activity since the industrial revolution is causing global warming. Figure 11.3 shows the changes in global temperatures since 1880. The use of coal, oil, and natural gas, together with burning and clearing forests, is resulting in increases in the levels of carbon dioxide, methane, and nitrous oxide (Table 11.2). These greenhouse gases (GHG) are thought to result in the increases in global temperature (Figure 11.3).

Is Global Warming the Same as Climate Change?

The terms are often used interchangeably but they are not the same. According to the National Oceanic and Atmospheric Administration (NOAA), global warming is the change in surface temperatures of the world. Climate change is a broader term including global warming together with glacier melting, rising sea levels, and trends in weather such as the number and severity of draughts, hurricanes, and rainstorms.

Table 11.2 Changes in atmospheric concentration of greenhouse gases (GHG).

Gas	Global warming potential (GWP)[4]	Atmospheric conc. 1800[1]	2015
Carbon dioxide (ppm)[2]	1	280	400
Methane (ppm)[2]	72	0.7	1.8
Nitrous oxide (ppb)[3]	289	260	330

[1] Prior to the industrial revolution.
[2] ppm = parts per million
[3] ppb = parts per billion
[4] GWP uses carbon dioxide as a reference and figures are given for a 20-year timeline.

Data from NASA and US EPA.

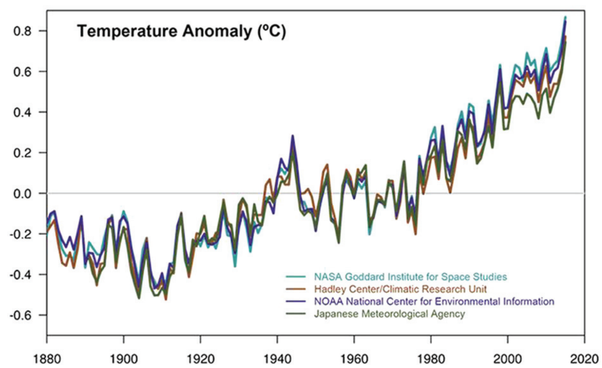

Figure 11.3 Changes in the global temperature as a temperature anomaly relative to a reference point/long term average or baseline from the mid-20th century. (Data sources: NASA's Goddard Institute for Space Studies, NOAA National Climatic Data Center, the United Kingdom's Met Office Hadley Centre for Climatic Research Unit, and the Japanese Meteorological Agency.)

According to the United Nations Food and Agriculture Organization, livestock and poultry production is responsible for 18% of anthropogenic GHG emissions (9% of global CO_2, 37% of CH_4, and 65% of N_2O). The details of the global agricultural activities that are producing GHG are summarized in Table 11.3. According to the EPA, in 2014 net GHG emissions in the United States were 6,870.5 million metric tons (MMT) (6.87 billion metric tons or BMT) with agriculture contributing 8.3%. Table 11.4 summarizes net emissions of GHG in the United States and the contribution of agriculture to net GHG emissions.

Greenhouse Gas

The term *anthropogenic*, when referring to greenhouse gas emissions or removals, refers to those that are "a direct result of human activities or are the result of natural processes that have been affected by human activities" (US EPA, 2016). The units used are:

- Mt or megaton = million metric tons (MMT) = Teragram (Tg) or 10^{12} g
- Gt or gigaton = billion metric tons = Petagram (Pg) or 10^{15} g

Greenhouse gas equivalents are expressed relative to the global warming potential of carbon dioxide (CO_2).

TEXTBOX 11D

Points for Discussion

The vast majority of scientists consider that global warming is occurring and that it is due to human activity. This is supported by the United Nation's Intergovernmental Panel on Climate Change (IPCC) and US government agencies including NASA and NOAA. Examples of scientific professional societies that have taken a position that global warming exists and is due to anthropogenic (human caused) activities include the American Association for the Advancement of Science, American Chemical Society, American Geophysical Union, American Medical Association, American Meteorological Society, The Geological Society of America, and US National Academy of Sciences. The arguments for global warming include the following:

1. The mean global temperature is increasing (see Figure 11.3).
2. Atmospheric concentrations of greenhouse gases are increasing (Table 11.2).
3. Alignment of models of the global climate, greenhouse gases, and global temperatures.

There are also climate change skeptics in the scientific community. The term "climate change deniers" will not be used because it is a pejorative. Their arguments include the following:

1. The greenhouse gases are only at trace levels (however traces can still be critical for toxins and trace levels of carbon dioxide are essential to plant growth and hence all animal life).
2. Climate has changed naturally in the past.
3. Global temperature figures are unreliable and/or the changes are small.

For further study, readers are encouraged to review a range of scientific articles about climate change/global warming from reputable sources.

The environmental impact of production (GHG footprint) of various livestock products per kilogram is greatest with beef, then pork, and then chicken meat (Table 11.5). These in turn are higher than for milk or eggs due to the water content. Table 11.4 provides a comparison of the GHG emissions from different sectors of animal agriculture per unit of protein. As poultry production has become progressively more efficient, GHG emissions have become progressively less.

Table 11.3 Total agricultural contributions to global warming in the world.

	GHG Released (Gt of CO_2 Equivalents GHG)
Land-Use and Land-Use Change [Forest and Other Natural Vegetation Replaced by Pasture and Feed Crops and CO_2 from Soils (Pasture and Arable Land Producing Feed)]	2.5
Feed Production [Chemical Fertilizer Including Manufacture and Application for Feed Crops (CO_2, N_2O, and NH_3)]	0.4
Animal Production [Ruminant Enteric Fermentation (CH_4) and On-Farm Fossil Fuel Use	1.9
Manure Management (CH_4, N_2O, and NH_3)	2.2
Processing and Transport	0.03
Total	**7.03**

Data from United Nations Food and Agriculture Organization.

Table 11.4 The contributions of agriculture to greenhouse gas (GHG) emissions in the USA in 2015.

Sector*	Percentage Contribution
GHG total	
Electricity generation	29
Transportation	27
Industry	21
Commercial and residential	12
Agriculture	9
Carbon dioxide**	
Electricity generation	35
Transportation	32
Industry	15
Residential and commercial	10
Other	7
Methane	
Natural gas and petroleum production	31
Ruminant enteric	25
Landfills	18
Manure management	10
Coal mining	9
Other	7
Nitrous oxide	
Agriculture—Soil management including fertilizers	75
Combustion	7
Industry including chemical industry	6
Manure management	5
Transportation	5
Other	2

* Forestry and land use is a net sink of GHG and accounts for 11.8% of GHG emissions.
** Respiratory carbon dioxide by livestock and poultry are not included.
Data from US EPA.

Table 11.5 Feed conversion and GHG emissions from the island of La Réunion.

	Feed Conversion Efficiency (kg Concentrate kg Product^{-1})	GHG Emissions (kg CO_2-eq. kg^{-1} Protein
Beef (Fattening)	5.48	104.7
Milk	0.79	87.3
Pork	3.23	35.9
Chicken Meat	2.19	25.9

Based on Vayssieres et al., 2010.

TEXTBOX 11E

A Deeper Dive: Poultry and Greenhouse Gases

The GHG footprint of poultry production varies around the world. For instance, production in the United Kingdom will have a higher GHG footprint due to the high GHG footprint of soybean meal imported from South America (9–15 kg of CO_2 equivalents kg^{-1}); the high GHG footprint is due to emissions from land-use change together with the footprint related to transportation (Taylor et al., 2014). Similarly, the GHG footprint of poultry production in Latin America would be high due to both corn (maize) and soybean production on land formerly forested that had been cleared for growing crops.

The GHG footprint of egg production in the United Kingdom was estimated at 2.2 kg of CO_2 equivalents per dozen eggs (1.6 kg of CO_2 equivalents kg^{-1}) (Taylor et al., 2014).

Production Systems and GHG Production

The GHG footprint has been estimated to be increased in free-range but not organic poultry production by, respectively, 20% for chicken meat and 15% for eggs (Williams et al., 2006).

Approaches to Mitigate GHG Production

Increased efficiency of poultry and crop production can reduce the environmental impact of poultry production. For instance, there was calculated to be a 71% decrease in GHG emission per ton of eggs from 1960 to 2010 and a 60% reduction in GHG emissions for pullet production (Pelletier et al., 2014) (see Textbox 11E Table 1). Shifts to alternative protein sources could potentially reduce the GHG footprint of poultry production. Such sources include algae produced to absorb carbon dioxide from industrial systems and worms produced in the process of vermiculture by composting animal waste (Taylor et al., 2014).

Textbox 11E Table 1 Changes in the GHG emissions with layers between 1960 and 2010.

GHG Emissions	1960	2010
Pullets (t CO_2 equiv. per 1000 pullets)	13.5	5.4
Eggs (t CO_2 equiv. t^{-1} eggs)	7.2	2.1

Pelletier et al., 2014.

11.6 Poultry, Nitrogen, and Water Quality

Nitrogen cycling is summarized in Figures 11.4 and 11.5. Nitrogen in the form of ammonium ions is taken up by plants and converted to amino acids and then to proteins. Plant proteins are taken in by poultry and converted to animal proteins. Nitrogen metabolism in poultry also results in the waste product uric acid. The uric acid is then degraded to form ammonia. The nitrogen in synthetic fertilizers is produced chemically from atmospheric nitrogen.

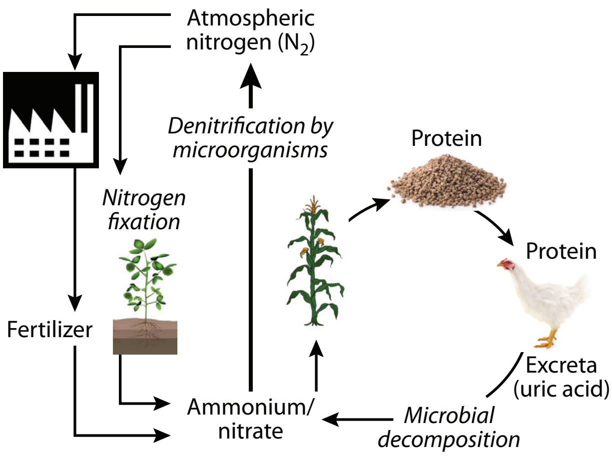

Figure 11.4 Relationship between poultry and the nitrogen cycle.

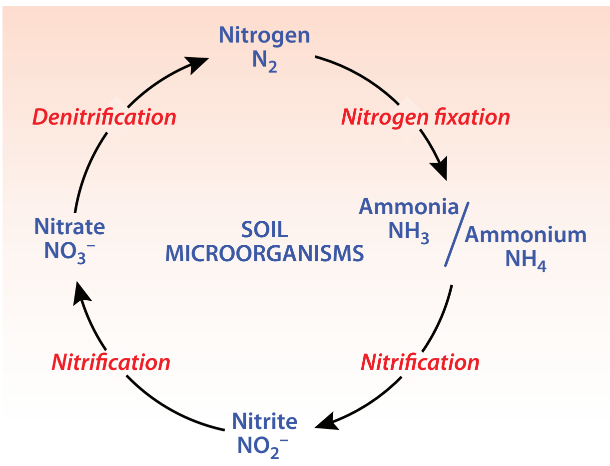

Figure 11.5 The chemical nitrogen cycle.

Nitrogen as ammonia or nitrates can leach into surface or groundwater and hence to waterways and the oceans, as can nitrogen from commercial fertilizer (e.g., anhydrous ammonia). There is evidence that excess concentrations of this nitrogen allow multiplication of microorganisms, leading to very low oxygen tension with water (hypoxia) such that animal life cannot survive (e.g., the "dead zone" in the Gulf of Mexico).

Ammonia Emissions

Nitrogen as ammonia may be lost as either a gas or absorbed onto dust and released into the air. The ammonia may be redeposited into the land and can be a noxious odor to neighbors. According to the US EPA, ammonia emissions from animal production in the United States in 2015 are as follows:

- Cattle (milk and beef)—1.14 million metric tons (MMT) or teragram (Tg)
- Poultry (broilers, layers, and turkeys)—0.65 MMT or Tg
- Pigs—0.46 MMT or Tg

There is a loss of ammonia from poultry houses due to microbial decomposition of uric acid and residual protein in the excreta. For broiler chickens, ammonia is lost from the litter. In addition, ammonia is released from storage of spent litter and during land application. Total losses of nitrogen as ammonia can be over 25%. The US EPA estimates that losses of ammonia from broiler chickens are 100 g (0.22 lb) NH_3 year^{-1} head^{-1} or 508 g (1.12 lb) NH_3 year^{-1} head^{-1}. When poultry manure is held in anaerobic lagoons, nitrogen will be lost as either ammonia or, following oxidation at the surface, as nitrogen gas.

Potential Remedies

It is possible to reduce nitrogen in poultry excreta by providing the birds with diets where the amino acids are balanced to meet the nutritional needs of the bird at the specific phase of growth or egg production. This is referred to as the "ideal protein." The ideal protein is defined by the National Research Council as "the balance of indispensable amino acids that exactly meets the animal's requirements with no deficiencies or excesses." The ideal protein potentially provides an approach to reduce nitrogen excretion. It is estimated that idealizing poultry diets could reduce nitrogen in excreta by about 35%.

11.7 Poultry, Phosphate, and Water Quality

The phosphate cycle is shown in Figure 11.6. Phosphorus is an essential nutrient that is obtained from plants, bones, and minerals. Much of the phosphorus in poultry diets is in the form of phosphate bound to plant sugars—to phytate. This phytate phosphorus is not digestible and hence passes through the bird's gastrointestinal tract with the feces. This represents a dual problem in that inorganic (digestible) phosphate has to be added to the feed and that phytate phosphate is found in the excreta. The phytate is degraded by soil microorganisms, thereby releasing the phosphate.

Phosphate is a potential environmental hazard. If manure is applied to land at levels above those that can be taken up by growing crops, the phosphate builds up in the soil. There is considerable potential for phosphate getting into runoff water, surface water, watersheds, and then rivers. While some dissolved phosphate leaches into the surface and groundwater, the majority of phosphate enters waterways attached to soil and other particles. It can then leach off.

Phosphorus pollution of waterways can be of agricultural (manure or inorganic phosphorus fertilizer), industrial, or domestic (e.g., phosphate-containing detergents) origins. Irrespective of origin, phosphate in waterways is a critical problem. Eutrophic organisms, particularly algae, require phosphate. In the presence of enough phosphate, the eutrophic organisms multiply rapidly (see Figure 11.7). These use up the oxygen dissolved in the water such that fish and other animals die.

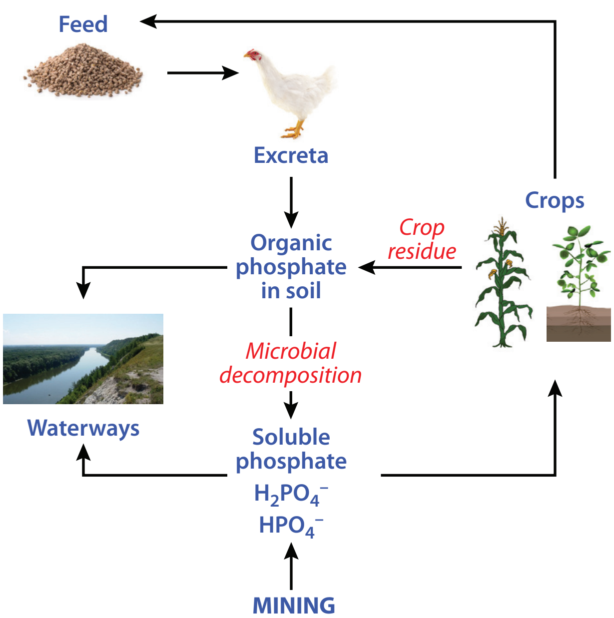

Figure 11.6 Relationship between poultry and the phosphate cycle.

What Is Eutrophication and How Is It Related to Phosphate?

The autotrophs convert carbon dioxide to their constituents using photosynthesis. They require inorganic phosphate. When there are high concentrations of inorganic phosphate in waterways, lakes, and ponds, autotrophs (algae and cyanobacteria) multiply to very high populations. These have high rates of respiration such that at night there is a precipitous decrease in the level of oxygen in the water. In turn, this leads to the death of animal life such as fish. The dead animals then decompose, releasing plant nutrients and these, in turn, feed more autotrophs.

The amount of phosphorus in the excreta is also a problem since state and federal regulations are moving toward a "phosphorus standard" for land application of manure. The more phosphorus, the more land is required to apply manure. This creates logistical problems and increases the transportation costs.

Potential Remedies

If phytate phosphate is reduced in feed, the amount of phosphate in the excreta will decline in essentially a "one to one" arrangement. Phosphate in phytate can be released by treatment of feed with the microbial enzyme phytase. The phosphorus is then available to the bird. Therefore, the amount of phosphorus in the diet

Figure 11.7 Eutrophication in a stream. (Source: Pumidol/Shutterstock)

needs to be decreased. An alternative approach is to use low-phytate corn (maize), which has less phosphate that is much more available or digestible. This approach decreases phosphorus in the manure.

11.8 Other Impacts of Poultry on Water

The poultry industry is a significant user of freshwater or blue water. The latter is fresh surface and groundwater (i.e., in lakes, rivers, and aquifers). According to the US Geological Survey, while agriculture as a totality is a significant user of water, livestock (including poultry) only account for 1% of all agricultural use.

- Thermoelectric 45%
- Irrigation 33%
- Public supply 12% including domestic use 1%
- Industrial 4%
- Aquaculture 3%
- Livestock 1%
- Mining 1%

11.9 Relationships with Neighbors and Communities

Having good relations with neighbors and communities is important because (1) it is good manners and the right thing to do, (2) it facilitates cooperation, and (3) it improves public relations and consumer confidence. (The saying that all publicity is good publicity does not apply to animal agriculture or to any food!) Among the issues that can disturb neighbor and community relations are odors, rodents, and flies. Where building permits are required, good community relations can be very important.

Odors, Rodents, and Flies

Odors around poultry facilities can irritate neighbors. Issues include particulates and ammonia. Rodents associated with poultry facilities can represent a problem as well (discussed in Chapter 10). Rodents are associated with disease and a lack of sanitary conditions and people do not want rats or mice in or near their homes. Minimizing rodent populations is not only good business practice for the poultry producer but also essential for a good-neighbor policy.

Flies (e.g., the common housefly—*Musca domestica*) are a nuisance that can be associated with poultry production. Neighbors can easily be disturbed by large numbers of flies coming from nearby poultry houses. Concerns with flies include their association with disease, spoilage of food, and the unpleasant sounds made by flies around the house, at barbecues and picnics, and during other outdoor activities.

Manure Application

It is prudent to discuss with neighbors about the timing of land application of spent litter or manure, avoiding times when neighbors have family gatherings, weddings, or outdoor activities planned.

Siting Poultry Facilities

Pollution control is the first and most important requirement in locating a new poultry establishment or in expanding/renovating an old one. The location should be such as to avoid (1) neighbors complaining about odors and insects and (2) pollution of surface and underground water. Without knowledge of pollution control and the required permitting, no amount of capital, native intelligence, and sweat will make for a successful poultry enterprise. Beautification such as growing trees around facilities can also be helpful to neighbor and community relations.

☐ References and Further Reading

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12

Stress and Welfare of Poultry

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List the major components of the response to stress.
2. Know the ways for measuring stress.
3. Know what the hypothalamo-pituitary-adreno-cortical axis is and why it is important for stress.
4. Understand why stress impacts performance.
5. Understand the difference between stress and the fight-or-flight response.
6. Understand the issues related to poultry welfare.
7. Know the ways of measuring welfare.
8. List the "Five Freedoms."
9. List the United Egg Producers' recommended practices.
10. List the National Chicken Council requirements.

12.1 INTRODUCTION

This chapter will briefly cover stress in poultry and issues of poultry welfare. While there has been tremendous progress in poultry production, there are ongoing concerns from the public about the welfare of poultry and other livestock. Moreover, it is not clear the extent to which essential physiological, behavioral, and other adaptive mechanisms (heat, respiration, etc.) have always kept pace with genetic improvements in production indices.

12.2 STRESS

Overview

Stress is physiological, physical, or psychological tension or strain and affects birds, including poultry. Social stresses are those changes in social behavior and population density that may influence growth and reproductive performance. Among the environmental factors that stress poultry are temperature, nutrition, disease, space per bird, social stress, gathering for market, and transportation. An example of social stress is mixing unfamiliar chickens together. This is not only associated with aggressive behavior but also increases in physiological indicators of stress, such as the adrenal hormone corticosterone. Moreover, there are other changes in behavior such as a decreased pecking at feed. Generally stress is associated with physiological changes such as increased blood levels of the "classical" stress-related adrenal cortical hormone corticosterone (CORT); increased blood levels of epinephrine (adrenaline) and norepinephrine (noradrenaline); and an increased heart rate. Moreover, there are behavioral changes such as immobility.

Stress activates the hypothalamo-pituitary-adrenal cortical axis (see Figure 12.1).

Hypothalamus
↓ Corticotropin-releasing hormone (CRH)
Anterior Pituitary Gland
↓ Adrenocorticotropic hormone (ACTH)
Adrenal Cortical Cells
↓ Corticosterone (CORT)
Physiological Changes

The hormone CORT orchestrates the physiological changes necessary to adapt to the stress. Physiological changes induced by CORT include the following:

- Circulating concentrations of glucose ↑
- Liver glycogen ↑
- Adipose tissue (e.g., abdominal fat pad or leaf fat) ↑↑
- Growth ↓
- Breast muscle weight ↓

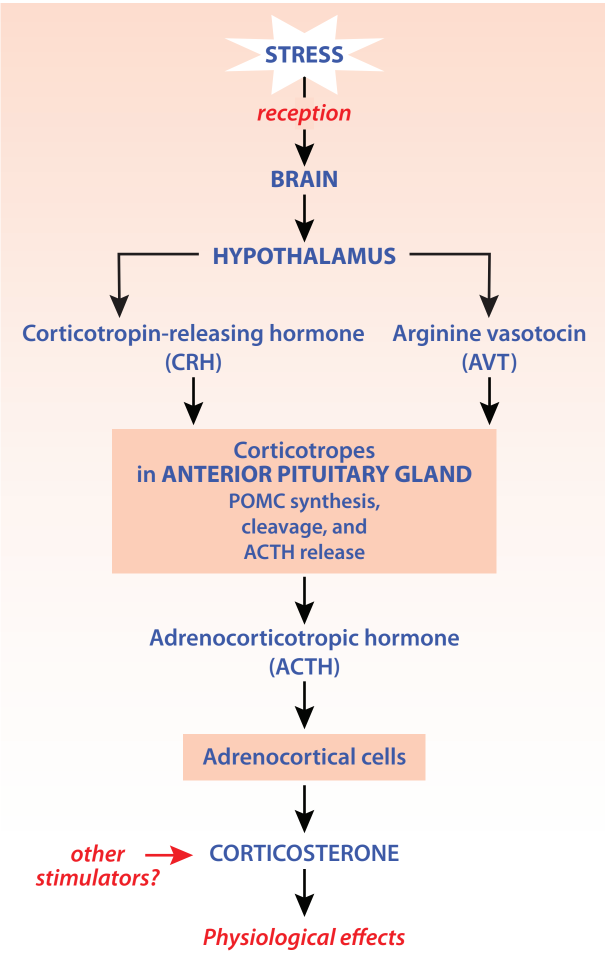


Figure 12.1 How the effects of stress are mediated by the hypothalamo-pituitary-adrenal cortex. POMC is proopiomelanocortin.

Factoids on Adrenal Cortical Hormones

Do People Have Corticosterone?

In humans, livestock, and companion animals the major hormone from the adrenal cortical cells is cortisol. In birds and rodents, corticosterone is the major adrenocortical hormone. Corticosterone and cortisol are both glucocorticoids (hormones that influence carbohydrate metabolism). In addition, glucocorticoids suppress the immune system and reduce inflammation. The latter property is employed in drugs we use, such as in Cortaid, an anti-itch cream.

Are There Differences with Glucocorticoid Production in Poultry and Mammals?

In mammals, the cortical cells are found in one area of the adrenal glands—the adrenal cortex. In poultry and other birds, the cortical cells are found mixed with the chromaffin cells (producing epinephrine and norepinephrine) throughout the adrenal glands.

The Concept of Stress

The word *stress* came to Middle English from the Old French word *estresse* (for narrowness, oppression) in about 1300. From physics and engineering, stress later gained additional meaning for putting a material under pressure or tension. Beginning in the 1930s, stress became a physiological/psychological term referring to mental strain and/or biological challenge. It was initially employed as an effective metaphor from its use in materials. This concept of stress as mental strain and/or biological challenge was incorporated into the general adaption syndrome (GAS) (see Figure 12.2). The GAS model of stress was developed by Hans Selye between 1936 and 1956 and incorporated the idea that the stress hormone is cortisol or corticosterone. The word stress was initially used to include the fight-or-flight response (in response to danger) developed by Walter Cannon in the 1930s.

Fight-or-Flight Response

The fight-or-flight response was developed based on observations of cats that were exposed to dangers or perceived dangers (e.g., dogs). This is seen broadly in mammals and birds. In the fight-or-flight response, the animal releases norepinephrine and epinephrine from the adrenal medulla and the sympathetic nervous system. These act to increase blood flow to critical organs such as skeletal muscles.

In chickens, the administration of epinephrine is followed by the following (Wideman, 1999):

- Mean arterial blood pressure ↑
- Peripheral resistance ↑ due to vasoconstriction (contractions of smooth muscle in the vasculature)
- Cardiac output ↓
- Stroke volume ↓
- Heart rate ↓

Stress and Production Indices

Stressed poultry and livestock are not functioning at their maximum. There is, therefore, a strong incentive for producers to minimize stress and hence maximize both production and profits. Key indicators that poultry are being raised with low stress and/or with a high level of welfare are production indices such as: (1) growth rate for broiler chickens and turkeys, (2) egg laying in laying hens, (3) the efficiency of production, and (4) the absence of morbidity and mortality. The following is a synthesis of the impact of stress on growth and carcass composition:

Stress → Hypothalamus/Pituitary gland → ACTH → Adrenal gland → Corticosterone (CORT) → Growth rate ↓/Breast muscle weight ↓

It is obvious that producers will want poultry produced under low stress to maximize production. However, people do not always follow what is in their economic best interest. Reasons for this can be a lack of knowledge, inadequate training, or even laziness. In addition, profitability is not necessarily based on the welfare of individual animals.

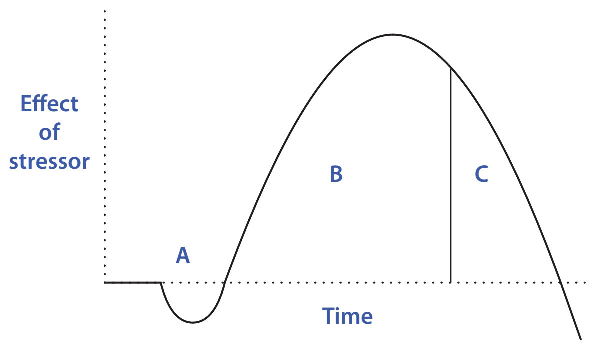


Figure 12.2 Schematic of the response to a stressor. A is an initial positive response, B is the resistance phase when the body of the poultry species is responding to the stressor, and C is the exhaustion phase when the animal is no longer able to respond to the stressor and stored resources are exhausted. This schema is based on Han Selye's General Adaptation Syndrome first published in 1936.

Measures of Stress

There are several physiological indicators of stress:

- Blood levels (plasma or serum concentrations) corticosterone (CORT). The higher the plasma concentrations of CORT, the greater the stress. Levels of CORT in excreta or feathers are also used.
- Leukocytes: The ratio of heterophils to lymphocytes (H:L ratio) with the higher the ratio, the greater the stress.
- Other indicators include heart rate or plasma concentration of epinephrine or norepinephrine and decreased eye temperatures.

Table 12.1 summarizes the effects of a series of stressors on both circulating concentrations of corticosterone and the ratio of heterophils to lymphocytes (H:L ratio).

12.3 Welfare

Overview

Today there is renewed interest in the study and application of animal behavior; we are trying to make it right with animals. For the time being, this calls for emulating the natural conditions of the species, including their space requirements, social organization, and train-

Table 12.1 Effect of stressors on circulating concentrations of CORT and heterophil: lymphocyte ratios in chickens.

	Circulating concentration of CORT	H:L ratio
Endotoxin	↑↑	↑
Heat	↑↑	↑
Cold	↑↑	→
Immobilization	↑↑	→
Shackling	↑↑	↑
Nutritional Restriction or Deprivation	↑↑	↑
Molting	↑↑	→
Handling and/or Transportation	→	↑

Adapted from Scanes, 2016.

ing and experience. It calls for breeding and selecting animals better adapted to artificial environments. It is hoped that the principles and applications of animal behavior presented in this chapter will speed the process.

It should always be the case that farmers and producers are concerned for the welfare of their animals. Animal and poultry scientists have repeatedly demonstrated that a severely stressed animal will not show good performance. Hence, it is not in the economic interest of the producer to have stressed animals. Moreover, virtually all producers are humane. There are considerable changes in the standards for raising and keeping poultry and livestock. A growing but still relatively small percentage of the public are concerned about the welfare of food animals, reflecting adverse publicity on factory farms and "battery" hens.

Concept of Welfare

The concept of welfare was initially applied to societies as the state of well-being or being in a satisfactory state. Another meaning of the word is financial support for the poor with welfare being a public policy designed to bring society into a satisfactory state. The meaning of welfare as "well-being" or "being in a satisfactory state" has also been applied to livestock and poultry.

Measures of Welfare

Indicators of welfare include (1) tonic immobility with manual restraint, with a greater length of time indicating fear or fearfulness; (2) latency to lie—a test of leg condition conducted in shallow water, with the shorter the latency to lie indicating that the condition of the leg(s) is worse; (3) the condition of the breast, foot pad, and hock. Other tests include asymmetry score or fluctuating asymmetry (e.g., tarsometatarsus length, tarsometatarsus width at spur, and outer-toe length), gastrointestinal lactic acid bacteria numbers, and low levels of mortality and morbidity. (In noncage systems for layer hens, increases in bone breakages such as keel bone disorders have been reported.) There appears to be a close relationship between circulating concentrations of corticosterone, heterophils: lymphocytes ratio, and tonic immobility.

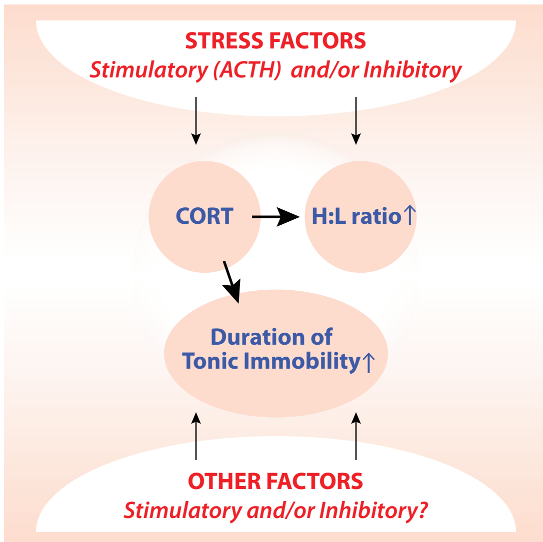
TEXTBOX 12A

A Deeper Dive: The Relationship between Different Indices of Stress

The administration of corticosterone is followed by increases in both H:L ratio and the duration of tonic immobility (Gross and Siegel, 1983; Jones et al., 1988).

CORT → H:L ratio ↑
CORT → Duration of tonic immobility ↑

There is evidence that the three metrics are related. Chickens with high tonic immobility (high fear) have elevated H:L ratios (Beuving et al., 1989) while circulating concentrations of CORT are depressed in low-fear chickens (Zulkifli et al., 2009). There are different amounts of glucocorticoid receptor in the hypothalamus between broiler chickens exhibiting short or long tonic immobility (Wang et al., 2014). However, all this evidence does not imply that corticosterone is the only cause of increased H:L ratio and the duration of tonic immobility (see Textbox 12A Figure 1). It is noted that there is not a uniform and consistent relationship between the responses of the three metrics to various stressors.



Textbox 12A Figure 1 Three common ways of assessing stress in poultry are plasma concentrations of corticosterone (CORT), heterophil to lymphocyte ratio (H:L), and tonic immobility with CORT influencing the other two.

TEXTBOX 12B

A Deeper Dive: Stressors, H:L Ratios, Asymmetries, and Tonic Immobility

There is some evidence that increased asymmetry is linked to reduced welfare but the responses are not consistently statistically significant (Knierim et al., 2007; Tuyttens et al., 2007). In contrast, there have been a series of studies where consistent results were obtained. These are discussed below.

Textbox 12B Table 1 summarizes the effects of stressor and enrichments on H:L ratio, asymmetry, and tonic immobility. Environmental factors expected to be stressful or impair welfare influence the metrics, with asymmetry lining up well with the expected welfare status. For instance, cold stress and continuous lighting was accompanied by increased asymmetry. However, continuous light increased both the H:L ratio and tonic immobility but cold stress did not affect either of these parameters (Campo et al., 2007; 2008).

Environmental factors that might be expected to improve poultry welfare include the availability of perches, auditory enrichment, and free range. These all reduce asymmetry (Campo et al., 2005; 2008; Dávila et al., 2011). This is consistent with low asymmetry reflecting high welfare. There were not consistent effects on H:L ratio or tonic immobility. There were reductions in H:L ratio in free-range chickens and those receiving auditory enrichment but no effects on tonic immobility (Campo et al., 2005; 2008; Dávila et al., 2011).

Textbox 12B Table 1 Impact of stressors on the heterophil:lymphocyte ratio (H:L), index of asymmetry, and tonic immobility.

Stressor	H:L ratio	Asymmetry	Tonic immobility
Cold stress	→	↑	→
Longer photoperiod (24L:0D vs 14L:10 D)	↑	↑	↑
Footpad dermatitis	→	_	↑
Free range versus conventional	↓	↓	→
Availability of perches	→	↓	↓
Auditory enrichment*	↓	↓	→
Colored string bunches and barley grains	→	→	→

*Classical music

Data from Camp et al., 2005; 2007; 2008; Dávila et al., 2011.

12.4 THE UNITED KINGDOM AND THE DEVELOPMENT OF WELFARE FOR POULTRY

The British government formed a committee led by Professor Roger Brambell to examine intensive livestock production. The findings were reported in 1965. This was followed up in 1979 when the British government established an advisory body on the welfare of livestock and poultry called the Farm Animal Welfare Council, which was replaced by the Farm Animal Welfare Committee (FAWC) in 2011. FAWC includes producers/farmers, veterinarians, animal scientists, animal behaviorists, ethicists, and members of animal welfare groups. The committee has stated that animals kept by man must be protected from unnecessary suffering. This encompasses both physical and mental well-being. The council has established the Five Freedoms as the framework for the establishment of standards of animal management/husbandry, environment (e.g., caging), handling, and humane slaughter (see sidebar).

The Five Freedoms

- Freedom from hunger and thirst.
- Freedom from discomfort.
- Freedom from pain, injury, or disease.
- Freedom to express normal behavior.
- Freedom from fear and distress.

These were developed by the Farm Animal Welfare Council, a committee established by the British government, which built on the Brambell Report. The Five Freedoms have been adopted by the World Organization for Animal Health (originally the Office International des Epizooties, or OIE) and form the basis of many audit programs worldwide.

12.5 Poultry Welfare Regulation in Different Countries

Animal Welfare and Government Policy

Government policies are best when they are science-based, being developed using published research. Policies for livestock and poultry are developed after bringing in animal and poultry scientists, veterinarians, physiologists, and ethologists (scientists studying animal behavior). Input from industry together with consumer and animal welfare organizations is also frequently sought.

Welfare and Poultry Production in the United States

In the United States, the poultry industry is addressing the issue of welfare. Traditionally, the industry has not liked the term *welfare*, preferring *bird comfort*. Obviously, for maximum productivity the birds' physical needs are being met through (1) high-quality feed, supplying all known nutrients; (2) clean water (checked regularly for impurities); (3) excellent management and care, with heat stress being reduced by tunnel ventilation (heat during transportation is still an issue though); and (4) unsurpassed poultry health programs.

Broiler chicks in the growing stages have the ability to exhibit behaviors such as eating, drinking, preening, and sleeping and are said to be free from fear, frustration, and pain. Many US broiler companies have established company-wide poultry welfare officers; poultry welfare councils with outside members; and standard operating procedures (SOPs) for brooders, growers, hatchers, and others to ensure welfare.

Rigorous animal welfare requirements are increasingly being set by the food industry after pressure from animal rights activists. For instance, McDonald's has stated its commitment to animal welfare and the humane treatment of animals. A scientific advisory committee was formed and goals for the humane treatment of laying hens were established. Space requirements are 72 sq. in. per bird together with 4 in. of feeder. Feed and/or water withdrawal to force molt has been prohibited and beak trimming is not supported. Inspections are carried out and suppliers not in compliance with the company's requirements have 30 days to correct deficiencies or cease to be suppliers. Similarly, in 2001, Burger King announced that it was requiring its suppliers to adhere to strict welfare requirements for the care, housing, transportation, and slaughter of poultry and other livestock. This is being "policed" with both announced and unannounced inspections or audits of facilities.

Textbox 12C

A Deeper Dive: Assuring Animal Welfare

PAACO (Professional Animal Auditor Certification Organization) is an organization that strives for standards of animal welfare. To achieve this, PAACO conducts audits of animal production facilities/farms (PAACO Minimum Standards for Assessments of Animal Welfare Audits). In addition, PAACO trains and certifies the auditors. PAACO views itself as "the standard of excellence in animal welfare auditing." Relevant auditors for poultry production in the United States include meat plant welfare auditors and poultry welfare auditors.

United Egg Producers is a producer organization that publishes *Animal Husbandry Guidelines for US Egg-Laying Flocks* as a set of recommendations for layer hens and their management. This is accompanied by a certification program. Other certifications include American Humane Certified™ from the American Humane Association, and Certified Humane Raised and Handled supported by ASPCA (American Society for the Prevention of Cruelty to Animals) and the RSPCA (Royal Society for the Prevention of Cruelty to Animals) in the UK.

In the United States, the Animal Welfare Act (1966) does not include farm animals. However, slaughter and transportation of poultry and livestock animals is covered by the Humane Methods of Livestock Slaughter Act (1958).

Industry Standards for the Welfare of Poultry

In 2002, the US food industry (the Food Marketing Institute, National Council of Chain Restaurants, and two major grocery chains) announced the introduction of standards for animal welfare. For laying hens, the United Egg Producers' practices are (1) an increase in cage space, (2) break trimming only to avoid cannibalism, (3) fresh feed and water requirements, (4) air ventilation requirements, (5) handling and transportation standards, (6) more humane molting procedures, and (7) daily inspection of birds to assure well-being.

The National Chicken Council has a series of requirements for broiler chicken production. These are described as the "Animal Welfare Guidelines and Audit Checklist." The requirements include the following:

1. Abuse of animals is never tolerated.
2. Demonstrable corporate commitment to animal welfare with top management needing to sign off on the company's animal welfare program, an identifiable group or individual responsible for animal welfare in the company, and an annual training program for all personnel handling animals.
3. On-farm best practices.
4. Feeding to provide proper nutrition.
5. Appropriate animal care in terms of housing, bird density, atmospheric quality (low levels of ammonia), and litter conditions.
6. Healthcare program under a veterinarian, with monitoring including inspection for wing and leg damage.
7. Humane catching.
8. Euthanasia for culled birds must be conducted in a humane manner.
9. Adequate temperature and ventilation during transportation.

These requirements are a model for broiler chicken production. In addition, it is recommended that there be comprehensive recordkeeping.

Welfare and Poultry Production in the European Union

The European Union (EU) has established rigorous welfare standards for cages for laying hens. Conventional cages (also referred to as "barren" cages) were banned after January 1, 2012. The directive allows producers to still use "enriched" cages. These have more space per hen and include a nest, a perch, and litter. Germany is going even further by requiring enriched poultry housing. Enriched colony housing includes perches, a dust bath area, and nests. Dust bathing is considered a "high priority behavior" by the EU.

The Welfare Quality program of the European Union uses a standardized assessment tool. This places importance on measures taken on animals (e.g., bodily condition, injuries, and fear). In addition, farmers should maintain high standards of hygiene, care (e.g., space and temperature), and management measures (e.g., handling and recordkeeping).

United Kingdom (Great Britain)

In the United Kingdom, the Royal Society for the Prevention of Cruelty to Animals (RSPCA) has supported the Five Freedoms by farm monitoring coupled with marketing labels of foods that meet the specific standards. The labels are called "freedom food." The British government has a code of practice that encourages removal of the sharp beak tip ("beak tipping") rather than trimming the beak.

12.6 Consumers and Poultry Welfare

Consumers can purchase poultry and eggs from conventional systems or organic or free-range systems or for eggs cage free. In addition, some stores have their own standards or use those of other groups. For instance, Whole Foods Market publishes standards for how animals (livestock and poultry) are raised:

1. No hormones (they are not used in poultry production).
2. No antibiotics: "Sick animals must get treatment, but meat from antibiotic-treated animals cannot be sold to Whole Foods Market."
3. Animal care follows Global Animal Partnership's 5-Step® Animal Welfare Rating system (see Chapter 3) with a certification program. The 5-Step® Animal Welfare Rating is made up of the following:

- Step 1 No cages, no crates, no crowding.
- Step 2 Enriched environment.
- Step 3 Enhanced outdoor access.
- Step 4 Pasture-centered.
- Step 5 Animal-centered, physical alterations prohibited.
- Step 5+ Animals live entire life on integrated farm.

The board of Global Animal Partnership includes leadership from various animal welfare organizations, including the Humane Society of the United States (HSUS) and the American Society for the Prevention of Cruelty to Animals (ASPCA), from Whole Foods Market, and from niche livestock producers. It does not seem to include anyone with poultry experience. Their goal for animals is natural living, good health, and a high quality of life and hope "to replace all fast-growing chicken breeds with higher welfare breeds by 2024." The positive experience can be summarized as follows: "At Global Animal Partnership, we believe that farm animal welfare isn't just about minimizing stress, suffering, and coping in an environment or being kept well-fed and watered. We believe farm animal welfare refers to the animal's quality of life."

TEXTBOX 12D

For Classroom Discussion

Why Is There Increased Public Concern about Animal Welfare?

- Is it simply irrational; not taking into account all the good farmers do?
- It is easy to criticize with a full stomach!
- Is it because direct links between people and production agriculture continue to be reduced? How does your experience of agriculture influence your views? Do you have relatives that are/were farmers? Are your parents farmers? Were your grandparents farmers? Were your great-grandparents? How typical are you?
- Is it because of bad behavior from a small number of producers/growers as seen in hidden camera videos?
- Is it because of activists and organizations promoting animal welfare or animal rights?
- Is it because of a lack of confidence in science and scientists? [Public skepticism of science and scientists]
- Is it because of increased intensiveness of production?
- Is it because larger and larger companies are controlling segments of poultry production (public distrust of large companies)?
- Is it because we anthropomorphize animals (i.e., think of them as if they are people)?

12.7 Companies and Poultry Welfare

Overview

Poultry welfare is critically important to poultry producers because (1) the consumer's demand for the product and their perception on its quality are affected by their view of animal welfare; (2) poor welfare reduces production metrics, such as growth rate, egg production, etc., and increases mortality; and (3) it is integral to corporate ethics.

Importance of Employees Treating Poultry Appropriately

Poultry must be treated appropriately because (1) it is morally right; (2) it is in the short- and long-term interest of the company and/or grower; and (3) exposure of poultry mistreatment leads to severe adverse publicity, opportunity costs with management devoting time to address problems, and the potential loss of sales. To achieve appropriate care and handling, poultry producers must hire the right people, focus on training and supervision, and not tolerate mistreatment.

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13

Diseases and Health of Poultry

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Know the difference between mortality and morbidity.
2. Discuss why diseases are important to commercial poultry production.
3. Understand the importance of diseases (pathogenic, parasitic, and metabolic) to poultry.
4. Know the classes of pathogens.
5. List pathogenic disease organisms (or pathogens) and the diseases that are caused by them.
6. Discuss the importance of vectors in disease transmission.
7. Know what coccidiostats are used for.
8. Understand what the consequence is of stopping use of ionophores as coccidiostats.
9. List the major components of the bird's immune system.
10. Understand how diseases are spread.
11. Understand the importance of biosecurity and sanitation programs.
12. Give the reasons for vaccination.
13. Know the major diseases in poultry where vaccination programs are routine.
14. Discuss the importance of metabolic diseases.
15. Name several metabolic diseases.
16. Understand the importance of environment and stress.

13.1 Overview of Poultry Disease

Healthy birds are a requirement for profit while unhealthy birds cause financial losses—this is well recognized by poultry producers. Deaths and condemnations result in economic losses. Animal health programs have reduced mortality, morbidity in diseased poultry, and poor performance (growth, etc.) where there are subclinical infections. In the 1920s, the mortality of growing poultry was about 18% (or even up to 100% in catastrophic disease outbreaks), but fell to 5% by 1975 and 4.5% by 2016.

Total mortality = mortality + number culled
(Number culled =
"On-farm condemnations" as diseased + moribund)

In village chickens in traditional rearing systems, mortality rises to over 30% (see Chapter 3). Between 2000 and 2015, the rates of condemnation of poultry carcasses at the processing plant in the United States decreased from 1.8% to 0.2%.

Definitions

Mortality: The rate of deaths, expressed as a percentage. The plural "mortalities" is the term used in the poultry industry for deaths.

Morbidity: The rate of overtly sick birds, expressed as a percentage.

Clinical disease: When birds are seen as sick.

Subclinical infection: When birds are not seen as sick but have an infection that may reduce growth, egg laying, and other aspects of performance.

Postmortem: From Latin, meaning "after death." This can refer to changes to organs after death or is used as a synonym for necropsy.

Taken together, clinical and subclinical infections cause greater losses than mortality to producers; there being decreased egg production or growth, lowered feed efficiency, and condemnations during processing. Disease prevention is critical to the success of the poultry industry in communities, regions, and nations throughout the world. There are critical roles for producers, integrators, state and federal governments, universities, and the animal health industry in disease prevention and control.

Normal Mortality and Morbidity Losses

In the broiler industry, mortalities run about 5% for the entire growing period. Increases above this indicate a problem. A rule of thumb regarding the evaluation of disease problems is if > 1% of the birds are sick.

Monitoring Health

It is important to know the normal so that you can recognize the abnormal. Signs of good health or disease are the following:

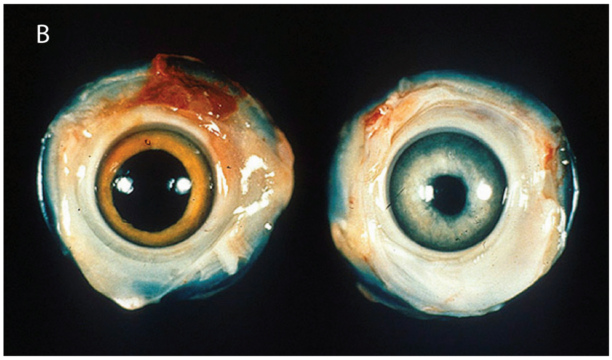
- Appearance of the birds.
- Amount of feed and water consumption.
- Rate of growth/egg production.
- Normal-appearing droppings.
- Physiological indicators: temperature 106°F (range 105°–107°F) (41°C), pulse rate (200–400 beats per minute), and rate of breathing (15–36 breaths per minute).
- General sounds and activity of healthy birds compared to droopiness and ruffled feathers in diseased birds.
- Lameness and gait.
- Watery excreta (diarrhea).
- Appearance of the skin (such as wounds or dermatitis).
- Appearance of the eyes (see Figure 13.1).

Symptoms of disease can be general (see above) while other symptoms are specific, seen only with certain diseases (e.g., discharge from the respiratory tract). There are also pathological changes in the structure of an organ (color, shape, etc.). These are macrolesions (large changes obvious to the trained eye) or histological microlesions (small changes only observable using a microscope).

13.2. Introduction to the Causes of Avian Diseases

Avian diseases are due to the following causes:

1. Pathogenic microorganisms (viruses, bacteria, and fungi) and parasites.
2. Nonpathogen-caused diseases including nutritional deficiencies (very rare in commercial poultry but seen in traditional and potentially in backyard flocks); genetic diseases (while these are very rare in commercial poultry, genetics can predispose commercial poultry to metabolic, pathogenic, and environmental diseases together with behavioral problems); metabolic diseases; environmental diseases (predisposing poultry to pathogen invasion and/or metabolic diseases); and behavioral prob-



A. Broiler chicken with coccidiosis.

B. Broiler recovering from cecal coccidiosis after treatment with a coccidiostat.

C. Irregular pupil of the eye of bird with Marek's disease (with eye lesions) (right) compared with normal chicken eye (left).

Figure 13.1 It is important to recognize disease in poultry. (Sources: A and B from Lucyin/Wikimedia Commons; C from USDA Agricultural Research Service.)

lems (predisposing poultry to pathogen invasion). This chapter will address pathogenic and non-pathogenic diseases, metabolic diseases, and environmental and behavioral problems in poultry.

Poultry Disease Factoid

Research on infectious disease in poultry are conducted in BL or BSL2 (biosafety level) facilities.

13.3 Pathogenic or Infectious Diseases

Pathogenic microorganisms in poultry include (1) viruses (causing viral diseases; see Table 13.1), (2) bacteria (causing bacterial diseases; see Table 13.2), and (3) fungi (causing fungal diseases; see Table 13.3).

In mammals, prions also cause disease. Stress (e.g., heat or cold, poor ventilation, overcrowding) predisposes poultry to infectious diseases. When microorganisms enter the cells of the body and multiply, they either disturb cell functioning directly or their toxins (poisons) affect the animal.

The ability of an organism to cause disease in a host is its virulence or pathogenicity (ability to cause disease). This can be altered (drastically reduced) to develop vaccines. Variation in pathogenicity also partially explains why the same disease may present different forms and degrees of severity. Infectious diseases of poultry are usually contagious. A contagious disease is one transmitted from one animal to another within a flock, from one flock to another, or to other animal species. A zoonotic disease is transmitted from animals to people. Some strains of avian influenza develop the capability to infect people and cause influenza. Infectious diseases are considered under viral, bacterial, and fungal diseases. Examples of poultry infected with various diseases are shown in Figures 13.1, 13.2, and 13.3.

Table 13.1 Examples of viral diseases of poultry.

Disease	Species	Causative Virus	Treatment	Prevention[1]
Avian influenza	Poultry	Avian influenza virus (AIV)	De-population	Biosecurity (potentially with vaccination)
Duck hepatitis	Ducks	Duck hepatitis virus (DHV)	None	Vaccination
Duck virus enteritis	Ducks	Anatid herpesvirus	None	Vaccination
Encephalomyelitis or Avian encephalomyelitis	Chickens	Avian encephalomyelitis (AE) virus	None	Vaccination
Fowlpox	Poultry	An avipoxvirus	None	Vaccination
Hemorrhagic enteritis	Turkeys	A type II Adenovirus	None	Vaccination
Infectious bursal disease (Gumboro)	Chickens	Infectious bursal disease virus (IBDV)	None	Vaccination
Infectious bronchitis	Chickens	Infectious bronchitis virus (IBV)	None	Vaccination
Laryngotracheitis or Infectious Laryngotracheitis	Chickens	Infectious Laryngotracheitis virus	None	Vaccination
Marek's disease	Chickens	Marek's disease virus (MDV)	None	Vaccination
Newcastle disease	Chickens and turkeys	Newcastle disease virus (NDV)	None	Vaccination

[1] Biosecurity is essential as is sanitation.

Table 13.2 Examples of bacterial diseases of poultry.

Disease	Species	Causative Organism and/or Agent	Treatment	Prevention
Anatipestifer disease or *Riemerella anatipestifer* infection	Ducks and turkeys	*Riemerella anatipestifer*	Antibiotics	Sanitation
Bacterial chondronecrosis (Femoral Head Necrosis)	Chickens	*Staphylococcus agnetis* and other bacteria*	Antibiotics	Greatly decreased with litter compared to wire flooring
Bordetellosis (turkey coryza)	Turkeys	*Bordetella avium*	Antibiotics	Vaccination
Botulism	Poultry	Toxin from *Clostridium botulinum*	Antitoxin	Ensure feed free of organism
Erysipelas	Turkeys	*Erysipelothrix rhusiopathiae*	Antibiotics	Vaccination
Fowl typhoid	Poultry	*Salmonella gallinarum*	Antibiotics	Ensure chicks are from *Salmonella-gallinarum*-free source
Mycoplasmosis	Poultry	*Mycoplasma gallisepticum* (chickens)	Antibiotics	Ensure chicks are free of *Mycoplasma*
Necrotic enteritis	Chickens	*Clostridium perfringens* (accentuated in presence of *Eimeria*)	Antibiotics	Cocciostats and vaccination
Paratyphoid	Poultry	*Salmonella pullorum* and *S. gallinarum*	Antibiotics	Sanitation
Pasteurellosis (fowl cholera)	Poultry	*Pasteurella multocida*	Antibiotics	Sanitation
Pullorum	Poultry	*Salmonella pullorum*	Antibiotics	Chicks from *pullorum*-free sources
Tuberculosis	Poultry	*Mycobacterium avium*	Antibiotics	Sanitation

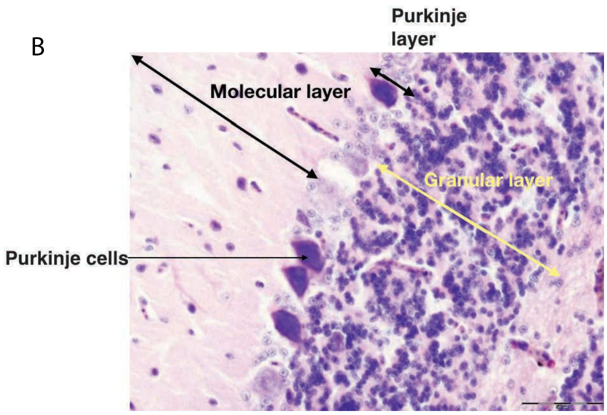
* Organisms present include; *Staphylococcus* spp., *Enterococcus* spp., *Escherichia coli*, *Salmonella* spp., *Streptococcal* spp.

Table 13.3 Examples of other infectious (nonviral and nonbacterial) diseases of poultry.

Disease	Species	Causative Organism and/or Agent	Treatment	Prevention
Aspergillosis	Poultry	Mycotoxin from *Aspergillus* mold	None	Sanitation
Coccidiosis	Chickens and turkeys	*Eimeria* (single-celled organism[1])	Cocciostats and vaccination	Removal of oocyte contaminated litter
Histomoniasis	Turkeys (severe) and chickens	*Histomonas meleagridis* (single-celled organism[1])	Nitarsone is somewhat effective	Placing poults in *Histomonas*-free and vector (*Heterakis* worms) free environment

[1] These have in the past been called parasitic protozoa.

A. Three mortalities from avian encephalomyelitis. Note the twisted neck (middle) and tetanus-like extended legs/feet (left and right).



B. Section through the cerebellum of a domestic turkey with avian encephalomyelitis showing necrosis (death) of Purkinje cells.

Figure 13.2 Avian encephalomyelitis mortality rates can reach 80–90%. (Sources: A, Lucyin/Wikimedia Commons; B, Roman Halouzka/Wikimedia Commons.)

Figure 13.3 A chicken with fowlpox. (Source: Ton Rulkens/Wikimedia Commons)

13.4 Viral Diseases

There are a large number of viruses that cause diseases in poultry (see Table 13.1). Viruses may contain either DNA or RNA as their genetic material and are so small that they cannot be seen through an ordinary microscope (they can be seen by using an electron microscope). They are also capable of passing through the pores of filters that retain ordinary bacteria and they propagate (multiply) only in living cells. In the case of RNA viruses, their genetic material RNA is copied to DNA before the viruses are replicated. Respiratory diseases affect the air passages, lungs, and air sacs and can be caused by viruses (e.g., avian influenza, infectious bronchitis, laryngotracheitis, and Newcastle disease). Other viral diseases produce lesions. Among them are some of the most devastating diseases of chickens and turkeys, such as avian encephalomyelitis (epidemic tremor), avian pox, leucosis, and Marek's disease.

Avian Influenza

Avian influenza (previously known as fowl plague) is a significant problem for poultry and game birds (see Figure 13.4). It is caused by type A influenza viruses (*Orthomyxoviridae*); these are RNA viruses (see Figure 13.5). There are two forms of avian influenza viruses that affect poultry: (1) highly pathogenic avian influenza (HPAI) viruses and (2) low-pathogenic avian influenza (LPAI) viruses.

Influenza A and B viruses cause seasonal influenza in people. Some come from pigs and others from birds. Type A influenza viruses can be assigned to different subtypes based on proteins on the virus surface: hemagglutinin (H) and neuraminidase (N). According to the Centers of Disease Control "there are 18 different hemagglutinin subtypes and 11 different neuraminidase subtypes (H1 through H18 and N1 through N11 respectively.)" For example, the HPAI viruses causing the outbreak of avian influenza in 2014–2015 was H5 with H5N2, H5N8, and H5N1 viruses in wild birds in flyways over North America.

Highly pathogenic avian influenza is not endemic in the United States and responds to eradication programs including flock depopulation. However, there have been serious outbreaks such as the 2014–2015 outbreak, with over 50 million poultry affected and indemnity costing the Federal government over $500 million. Low-pathogenic avian influenza is a chronic problem. In the United States, the federal government (USDA APHIS) indemnifies producers for losses after infected birds are euthanized and the eggs destroyed. Avian influenza vaccination is not routine in most of the world.

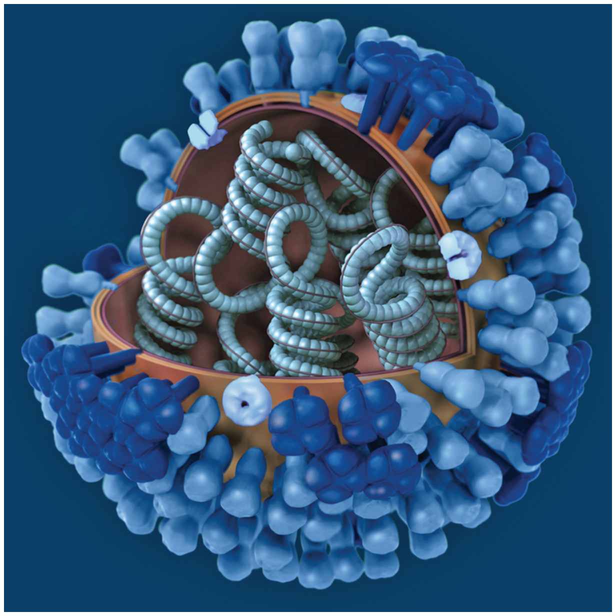


Figure 13.5 Conceptual structure of an influenza virion or virus particle. On the surface of the outer protein coat are hemagglutinin and neuraminidase proteins together with the matrix (M)2 ion channel crossing the viral wall. The interior with the RNA is shown in upper part of the image. (Source: Dan Higgins/Centers for Disease Control)

Figure 13.4 Turkey with avian influenza with the entire flock undergoing depopulation. (Source: Shpernik088/Wikimedia Commons)

Spring 2015 Outbreak of Highly Pathogenic Avian Influenza (HPAI) in the US

The economic impact of the spring 2015 outbreak of HPAI in the United States was over $1 billion. The virus responsible for this outbreak was a highly pathogenic avian influenza (HPAI) virus. The virus probably originated from wild migratory birds in Northern Asia and Alaska that had both highly pathogenic Asia AI viruses and low pathogenic North American AI viruses. There was then a reassortment of the virus genetics to produce HPAI viruses and huge losses.

Government Compensation or Indemnity Programs

Government compensation reduces financial losses when there is an outbreak of highly contagious diseases of poultry. This is in effect payment for people to act in the public interest and report diseases. Government compensation facilitates rapid depopulation and hence impairs the spread of pathogens.

In the United States, the Animal and Plant Health Inspection Service (APHIS), an agency in the US Department of Agriculture, provides indemnity or compensation to producers for losses of birds and eggs after depopulation due to an outbreak of HPAI. Compensation is up to the full fair market price but does not include losses of income or production or any other business disruptions. In addition, there is not indemnity for birds dying from HPAI. Indemnity requires that a biosecurity program is in place before the outbreak. The indemnity program provides "a formula to allow indemnity payments to be split between poultry and egg owners and their contracted growers" (USDA, 2016).

Avian Leukosis Including Marek's Disease

In the 1970s Marek's disease was relatively common, resulting in > 1% condemnations of broiler chickens. With vaccination, its impact has dropped 50-fold. The disease involves abnormal proliferation (cell division) of lymphocytes and their infiltration of organs such as the skin, muscle, and intestines, together with lesions in the pupil (see Figure 13.1C). The causative agent is the Marek's disease virus (MDV 1), a DNA herpes virus.

Avian Pneumovirus

The avian pneumovirus (an RNA virus related to the Newcastle disease virus) causes swellhead syndrome (chickens) and rhinotracheitis (turkeys). Symptoms of avian pneumoviruses include upper respiratory tract fluid secretion due to inflammation, with the virus stimulating cytokine release. In addition, interferons are released, which impair virus replication.

Newcastle Disease Virus

Newcastle disease was first observed in England and Indonesia in 1926. It is a disease of poultry affecting the respiratory and gastrointestinal tracts and nervous system (see Figure 13.6). It is widespread (endemic) in Africa, Asia, Europe, and South America, with sporadic outbreaks in North America. Live vaccines are used with attenuated or avirulent viruses. Exotic Newcastle disease is not endemic in the United States. The Newcastle disease virus (paramyxovirus or PMV 1) comprises six genes encoded in RNA. When an avian cell is infected, the RNA is translated to form viral proteins. Later, an antigenomic template RNA is formed as an intermediate for viral RNA replication.

Infectious Bursal Disease

Infectious bursar disease is a highly contagious disease that can cause rapid death or marked reduction in growth in young chickens. This is caused by an RNA virus—infectious bursar disease virus (IBDV 1).

Figure 13.6 Broiler chicken with Newcastle disease. (Source: L. Mahin/Wikimedia Commons)

13.5 Bacterial Diseases

Bacteria are the simplest forms of single-celled life. All bacteria are not detrimental to health; some may be involved in digestion. Bacteria can be classified as pathogens (disease-producing organisms) or harmless or beneficial. Table 13.2 provides a list of important bacterial diseases of poultry. Successful control of bacterial diseases entails preventing bacterial multiplication in the bird and the spread between birds. Bacterial respiratory diseases include chronic respiratory disease, coryza (roue), and infectious sinusitis of turkeys, mycoplasmosis.

Mycoplasmosis

Mycoplasma gallisepticum causes chronic respiratory disease in poultry (chickens and turkeys) and in wild birds. The disease is associated with respiratory signs (e.g., coughing), stunting or reduced growth, difficulty in walking due to infected leg (hock) joints, and reduced hatchability. It also increases the severity of other poultry diseases (e.g., viruses: IBV and NDV; bacteria: virulent *E. coli*, *Pasteurella* spp., and *Haemophilus*).

Necrotic Enteritis

Necrotic enteritis is due to the bacterium *Clostridium perfringens* coupled with coccidiosis. There is a T cell inflammation response and intestinal epithelial cell damage. *Clostridium perfringens* organisms (gram-positive, rod-shaped, anaerobic, spore-forming pathogenic bacterium) produce alpha, beta, epsilon, iota, and netB toxins. Poultry can be infected by type A *Clostridium perfringens* that produce A toxin. Necrotic enteritis results in rapid mortality together with lesions in the intestine and liver (see Figure 13.7). There is a growing problem of subclinical necrotic enteritis, which results in a lack of digestion of the feed and hence the feed passing straight through the intestinal tract.

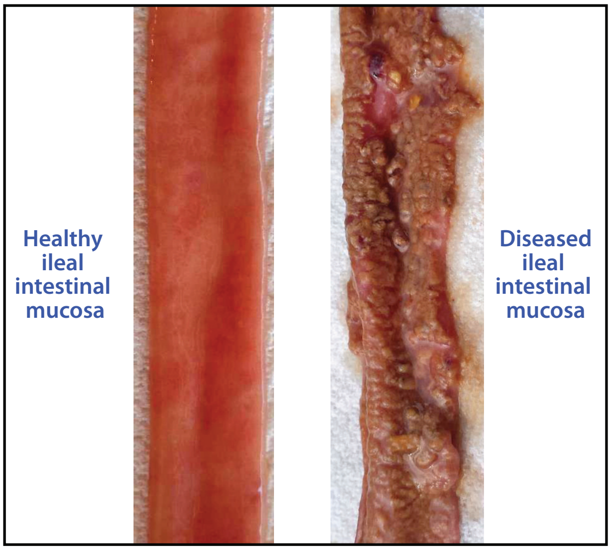


Figure 13.7 Necrotic enteritis due to *Clostridium perfringens* is becoming more of a problem for broiler chickens. The mucosal surface of the small intestine of an infected chicken shows marked abnormalities. Left: Healthy ileal intestinal mucosa. Right: Necrosis of the intestinal mucosal layer with presence of fibrin, hemorrhage, and necrotic debris in the ileum. (Source: Courtesy of Dr. Billy Hargis and Juan David Latorre Cardenas, University of Arkansas)

13.6 Fungal and Fungal Production (Mycotoxin) Diseases

Aspergillosis

Respiratory diseases can be caused by molds. A major example is aspergillosis, or brooder pneumonia, in young chickens (see Table 13.3). There are also effects on the brain (see Figures 13.8 and 13.9). The causative agent is normally *Aspergillus fumigates*, but *A. glaucus* and *A. niger* may be involved (see Figure 13.8 and 13.9).

Mycotoxins

Mycotoxins are toxins produced by fungi that can contaminate feed. In 1999, it was estimated that a significant proportion (25%) of the world's feedstuffs were contaminated. There are more than 300 mycotoxins. The most problematic are aflatoxin (from *Aspergillus* species), deoxynivalenol (vomitoxin; from *Fusarium* species), zearalenone (from *Fusarium* species), fumonisin (from *Fusarium* species), T_2 toxin (from *Fusarium* species), and ochratoxins *(Aspergillus)*. Mycotoxins depress growth in poultry. Growth in chickens is reduced by aflatoxin, cyclopriazonic acid, deoxynivalenol (vomitoxin), fumonisin B_1, and ochratoxin A.

13.7 Absence of Prion Diseases in Poultry

While prions (protein disease-causing agents) are thought to cause diseases in cattle, sheep, and people, there is no evidence that poultry have prion-induced diseases.

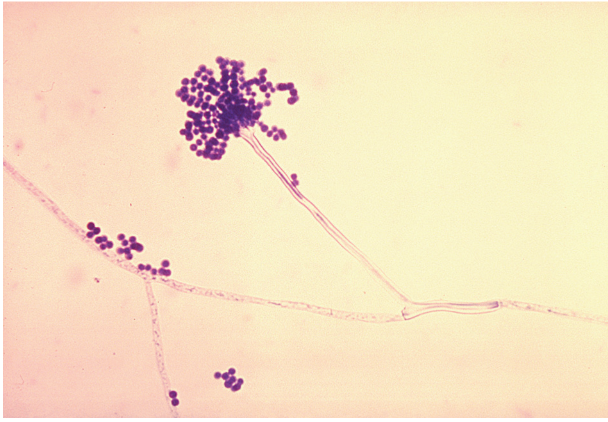


Figure 13.8 The disease-causing organism for aspergillosis or thrush is *Aspergillus fumigates* showing conidiophore phialoconidia. (Source: Centers for Disease Control)

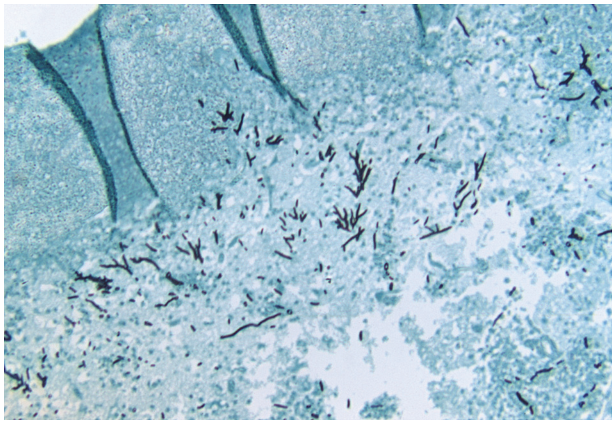


Figure 13.9 Silver-stained section through the brain of a turkey with aspergillus showing presence of fungal organisms—*Aspergillus fumigates.* (Source: Dr. Lucille Georg/Centers for Disease Control)

13.8 Introduction to Parasites

External and internal parasites affect poultry. Controlling parasites is a very effective way of increasing egg and meat production. Tables 13.3 (above) and 13.4 summarize the internal parasites of poultry with some major external parasites of poultry listed in Table 13.5.

13.9 Diseases Caused by Single-Celled Parasites

There are multiple diseases caused by single-celled organisms. Although many single-celled organisms are harmless, others produce severe diseases. These are frequently called protozoan diseases, with the pathogens being protozoa. Although this is widely used terminology, the term "protozoa" for single-celled organisms is not consistent with modern systematics. The single-celled organisms are now not considered in the Kingdom *Animalia.* Among the more common and serious single-celled diseases in poultry are the following:

- Coccidiosis. Causative agent: *Eimeria tenella* and other species of *Eimeria*. Organs affected: intestine. The life cycle of *Eimeria tenella* is shown in Figure 13.10.
- Histomoniasis or blackhead. This is found particularly in turkeys (economic damage more than $2 mil-

Table 13.4 Internal multicellular parasites of poultry.

Parasite	Species of Parasite	Poultry Species	Organ Infested
Flukes (*Trematoda*)			
Oviduct fluke	*Prosthogonimus macrorchis*	Chickens and turkeys	Oviduct
Round worms (*Nematoda*)			
Cecal worm	*Heterakis gallinarum*	Poultry	Ceca
Hair worm	*Capillaria contorta*	Poultry	Crop
Hair worm	*Capillaria obsignata*	Poultry	Small intestine
Large round worm	*Ascaridia galli*	Chickens	Intestines
Large round worm	*Ascaridia dissimilis*	Turkeys	Intestines
Tapeworms (*Cestoda*)			
Broad-headed tapeworm	*Raillietina cesticillus*	Poultry	Intestines
Small chicken tapeworm	*Davainea meleagridis*	Chickens	Intestines

lion in the United States; see Figure 13.11). Outbreaks in chickens have caused significant mortality though. Causative agent: *Histomonas meleagridis*. Organs affected: ceca and liver.

- Cryptosporidiosis. Causative agent: *Cryptosporidium bailyi* in chickens, *C. meleagridis* in turkeys. Organs affected: sinuses, trachea, bronchi, cloaca, and bursa.
- Trichomoniasis. Found particularly in pigeons where it is called canker, it is transmitted through crop milk. It can also affect chickens and turkeys. Causative agent: *Trichomonas gallinae*. Organs affected: upper digestive tract.
- Hexamitiasis. This once significant disease is now rarely found in turkeys in the United States. It also affects game birds and pigeons. Causative agent: *Spironucleus meleagridis*. Organs affected: upper digestive tract (duodenum and upper jejunum).
- Leucocytozoonosis. This is seen particularly in wild and domestic ducks and geese. Causative agent: *Leucocytozoon simondi* and other species of the genus *Leucocytozoon*. Organs affected: blood and internal organs.

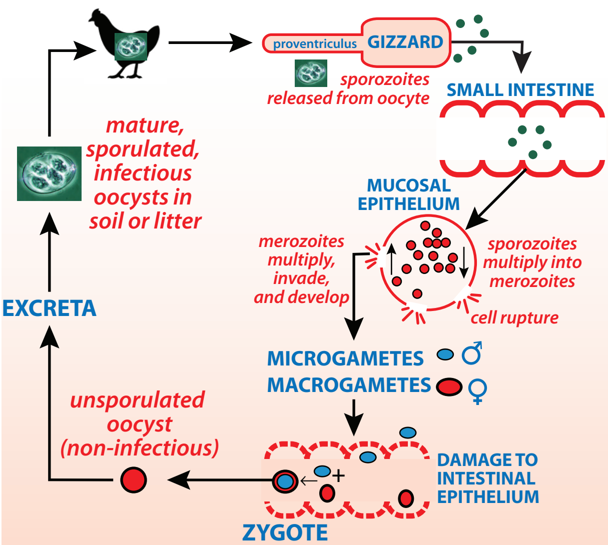


Figure 13.10 Turkeys are particularly susceptible to blackhead or histomoniasis. The causative agent is the single-celled parasite *Histomonas meleagridis*. The organism is shed as eggs from turkeys either alone or within the eggs of the cecal worm; the latter are much longer lived. The ingestion of the eggs leads to blackhead. The cycle of infection can be broken by disinfection, sanitation, and use of parasiticides that kill cecal worms.

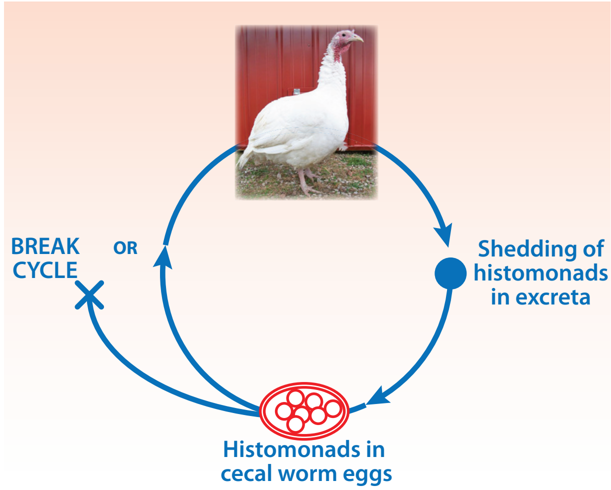


Figure 13.11 Simplified life cycle of *Eimeria*.

Coccidiosis

Coccidiosis is still one of the most common diseases of poultry. It is spread by the oocysts that can live in the excreta and are found in poultry houses. The oocysts are the infective form; they have thick walls and can remain in this quiescent form in the environment until eaten by poultry. The oocysts are easily transferred between poultry houses by personnel and equipment.

Coccidiosis can affect young chickens and turkeys with a major loss of growth rate. The *Eimeria* pathogens (Figure 13.12) invade cells of the intestine with, for instance, *Eimeria tenella* organisms being focused in the ceca of the chicken. The *Eimeria* are very species-specific, affecting only the host and possibly very closely related species. An estimated $3 billion is spent annually towards coccidiosis prevention worldwide ($90 million in the US) and decreased performance, morbidity, and mortality has a $300 million global impact.

Anticoccidial agents, such as the coccidiostats, are routinely added to both starter and grower diets. Ionophores, such as monesin and narasin, are considered antibiotics and cannot be used in antibiotic-free production systems. Instead, producers can use live coccidiosis vaccines, nonantibiotic coccidiostats, or coccidiostats in rotation (known as flock shuttling). Examples of nonantibiotic coccidiostats include decoquinate, diclazuril, nicarbazin, and robenedine hydrochloride.

Vaccines against *Eimeria* are available (e.g., Coccivac®) and are effective. For instance, *Eimeria* oocytes are shed 16 days after the Coccivac-B vaccination. In the

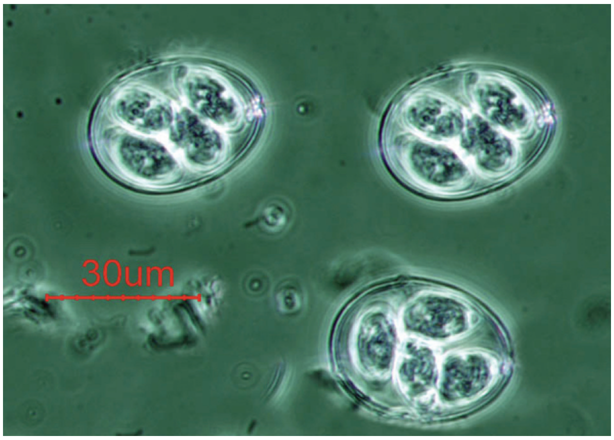


Figure 13.12 The infectious agent of coccidiosis are the single-celled parasites of the genus *Eimeria*, with *Eimeria maxima* being very important. Oocysts are found in the intestine and feces of poultry. (Source: USDA Agricultural Research Service)

presence of *Eimeria*, poultry are more susceptible to the bacteria *Clostridium*, resulting in necrotic enteritis that can lead to marked increases in mortalities (e.g., *Eimeria maxima* about 40% mortality). Similarly, there is evidence that mycotocins, such as deoxyvalenol and fumonisins, increase the severity of lesions in coccidiosis.

13.10 Other Internal Parasites (Roundworms, Tapeworms, and Flukes)

Overview

Poultry can also be infected with other internal parasites; if found in the intestine, these essentially rob the bird of nutrients. They can also invade other organs (e.g., blood and eye), destroying tissues. These parasites include roundworms (nematodes; organs affected include the digestive tract, eye, and other tissues), tapeworms (cestodes; affecting the digestive tract), and flukes (nematodes; organs affected include the digestive tract, liver, and other tissues). Wild birds are frequently the host to these parasites, and thus they can be spread. There are FDA-approved medications against many of these internal parasites.

The multicellular internal parasites are classified as (1) **roundworms**: phylum *Nematoda*, (2) **tapeworms**: phylum *Platyhelminthes*, class *Cestoda*, and (3) **fluke**: phylum *Platyhelminthes*, class *Trematoda*. Examples of internal parasites of poultry are nematodes, or roundworms. Roundworms negatively impact the growth of poultry. Infestation with nematodes is increased in free-range and pastured poultry. The problem can be resolved by the administration of anthelmintics (antihelminthic drugs). Use of these drugs in organic production is limited. There are at least three major types of nematodes infesting poultry (see Table 13.4):

- Large round worm (*Ascaridia galli* in chickens; see Table 13.4 and Figure 13.13). This is a large worm up to 4 1/2 in. long (12 cm). It is found in the intestine (ileum and jejunum) of chickens. The life cycle of *A. galli* is shown in Figure 13.14. In the presence of these nematodes there is increased incidence of diarrhea and growth rates are depressed.
- Hair worm (various species of *Capillaria* can be found in the intestine of all poultry along with some in the eye). These are about 12 mm long (1/2 in.) but only 0.05 mm wide.
- Cecal worm (*Heterakis gallinarum*). This worm is about 1/2 in. long (up to 1.5 cm). It can be found in the ceca of all poultry. The cecal worm is the principal vector transmitting the parasite *Histomonas meleagridis*. This is the cause of blackhead disease, a serious disease of turkeys. The life cycle of *Heterakis gallinarum* is shown in Figure 13.15.

Tapeworms

Tapeworms (see Table 13.4) are segmented and flat with a long ribbon-like appearance. They fre-

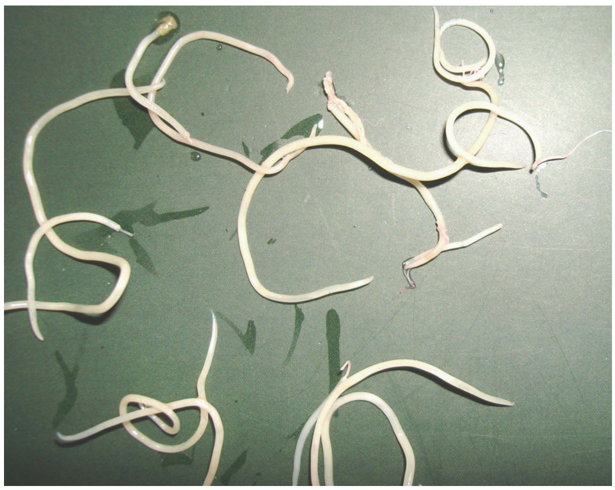


Figure 13.13 Nematode worms (*Ascaridia galli*) are parasites of the gastrointestinal tract of chickens. (Source: Chhandama/Wikimedia Commons)

TEXTBOX 13A

A Deeper Dive: Single-Celled Parasites in Poultry

Coccidiosis (*Eimeria*)

Coccidiosis is a very important disease of poultry. Textbox 13A Figure 1 shows the life cycle of *Eimeria*. This can be summarized as follows:

1. Chickens ingest sporulated oocysts from the litter or soil.
2. Sporozoites are released from the oocytes (8 per oocyte) due to mechanical effects of the gizzard and the actions of enzymes from, for instance, the proventriculus.
3. The sporozoites penetrate mucosal epithelial cells in the small intestine.
4. They undergo multiplication, producing large numbers of merozoites.
5. These merozoites are released when the epithelial cell ruptures.
6. The merozoites invade new epithelial cells and multiply.
7. The process of schizogony repeats about 1–4 times, causing significant damage to the small intestine.
8. Merozoites invade new epithelial cells and develop into the sexual stages—either microgametocytes (male) or macrogametocytes (female).
9. These produce microgametes and macrogametes, respectively.
10. The microgametes invade epithelial cells containing macrogametes followed by fertilization-forming zygotes.
11. The zygotes develop into unsporulated oocysts (noninfective).
12. These are released into the feces and undergo maturation to sporulated oocysts in the litter or soil.

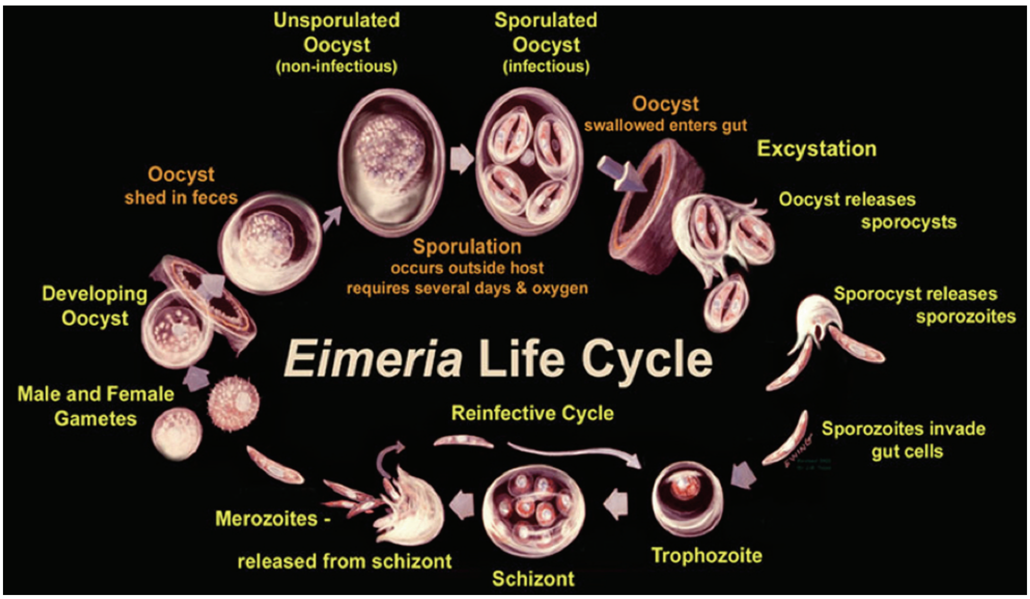
The disease organism infects the ceca and can damage other organs, including the liver (see Textbox 13A Figure 2 and Figure 3).

Histomoniasis (*Histomonas Meleagridis*)

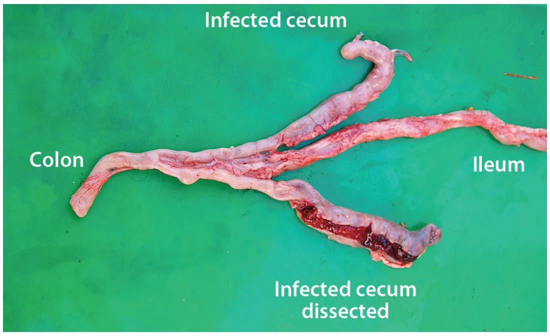
Histomoniasis is a poultry disease with liver (see Textbox 13A Figure 4) and cecal lesions and is caused by the single-celled parasite *Histomonas meleagridis*. It is transmitted by the eggs of cecal worm *Heterakis gallinarum*. Infection results in morbidity with mortalities/culling of about 10% in chickens but up to 100% mortality in turkeys (McDougald, 1998). Transmission is facilitated by access to the soil (Esquenet et al., 2003).

Cryptosporidiosis (*Cryptosporidium*)

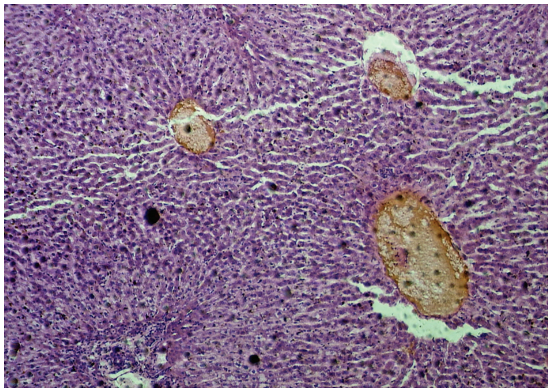
Cryptosporidiosis is another single-celled parasite of poultry that cause, for instance, respiratory cryptosporidiosis in turkey poults. The pathogen is a member of the genus *Cryptosporidium* and can be transmitted to people.



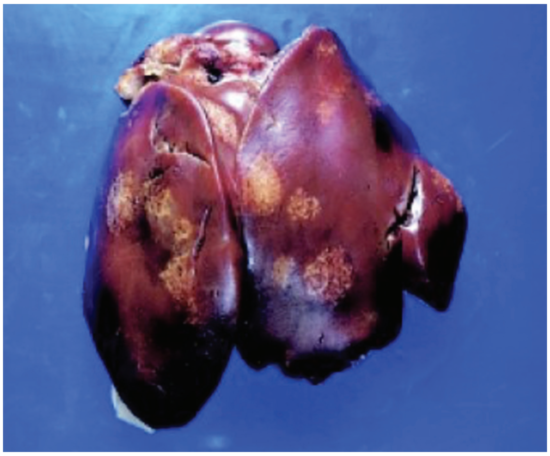
Textbox 13A Figure 1 Life cycle of *Eimeria*. (Source: USDA Agricultural Research Service)



Textbox 13A Figure 2 Ceca infected with *Eimeria* from a chicken with coccidiosis. (Source: Lucyin/Wikimedia Commons)



Textbox 13A Figure 3 Histological section through a liver infected with *Eimeria*. (Source: Ciência e Saúde XXI/Wikimedia Commons)



Textbox 13A Figure 4 Liver from a turkey infected by Histomonas showing pale diseased areas. (Source: Milton Friend/USGS)

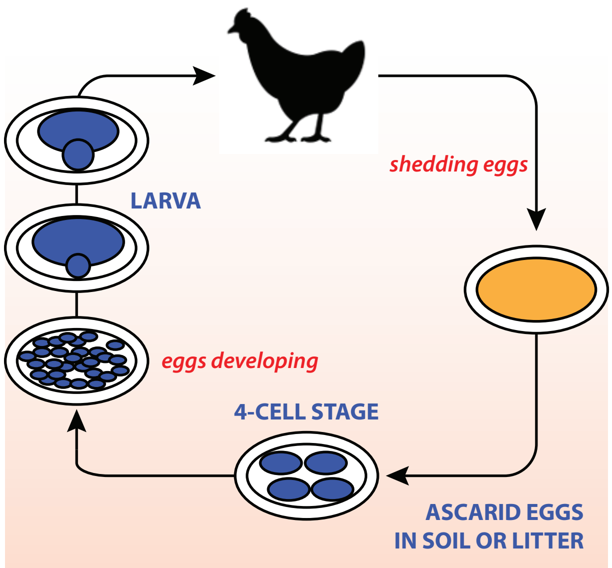


Figure 13.14 Life cycle of the round or nematode worm (*Ascaridia galli*), an intestinal parasite in chickens.

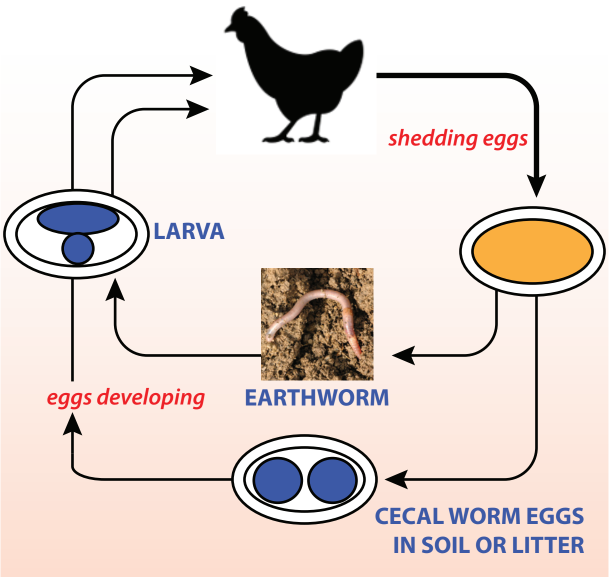


Figure 13.15 The life cycle of the cecal worm (*Heterakis gallinarum*).

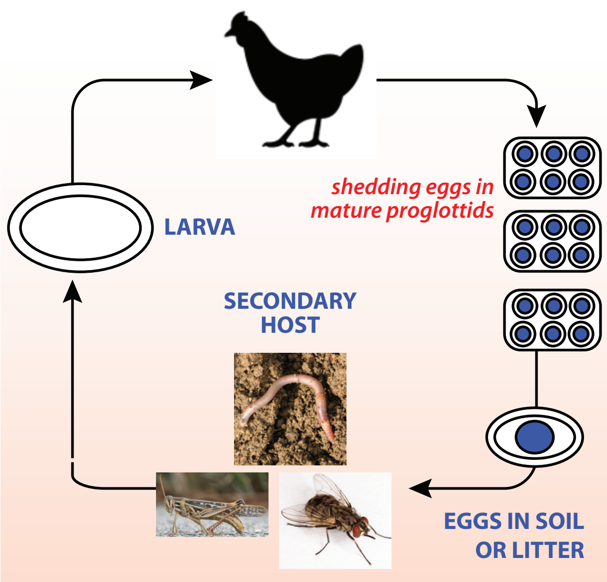


Figure 13.16 The life cycle of tapeworms. Poultry become infected by eating the intermediate host. (Sources: James Lindsey at Ecology of Commanster [earthworm]; www.birdphotos.com [grasshopper]; Stephen Ausmus/USDA [fly].)

quently infect chickens and turkeys in backyard flocks or on range conditions. The head or scolex is embedded into the tissue of the small intestine. The segments extend down the intestine. The lowest segments are called gravid and are filled with the infective eggs (or onchospheres). They are shed with the excreta. There may be an intermediate host such as beetles. The life cycle of tapeworms is shown in Figure 13.16. Among the ten species of tapeworms that infect chickens in North America and Europe is *Davainea proglottina*.

Trematodes

Trematodes, or flukes, can infect poultry. These flukes can infest organs such as the liver, pancreas, eye, and the oviduct (e.g., the oviduct fluke—*Prosthogonimus* sp.) (Figure 13.17). Flukes are not particularly species-specific and are found in multiple wild birds

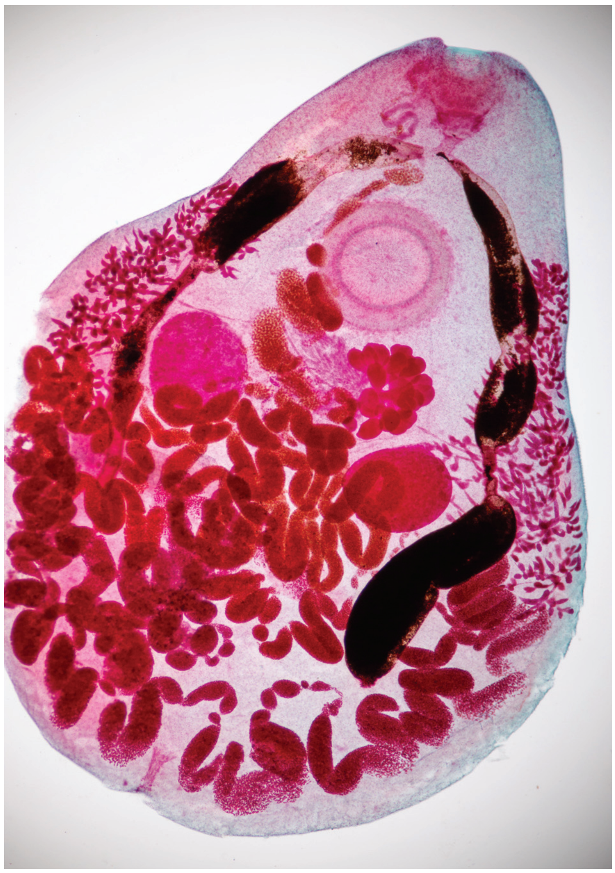


Figure 13.17 Section through an oviduct fluke (*Prosthogonimus macrorchis*). (Source: Piyapong Thongdumhyu/Shutterstock)

and poultry. Their intermediate hosts are snails and other molluscs. Since water is viewed as a media for infection, free-range poultry and particularly ducks are vulnerable to fluke infestation.

13.11 External Parasites and Bloodsucking Insects

Poultry are affected by external parasites (insects such as lice, arachnids such as ticks and mites) together with bloodsucking insects (bugs, mosquitoes, and beetles) (see Table 13.5). These cause reduced weight gain and egg production; mar the skin, resulting in downgrading of carcass quality; and act as vectors for the spread of infectious diseases. Heavy infestations can cause high mortality among young poults.

Insects

There are more species of insects on the planet than any other class of species. Among the numerous species are bees and butterflies, together with ectoparasites and bloodsucking insects. They are classified as: Phylum *Arthropoda*, class *Insecta*, order *Phthiraptera* (lice), order *Siphonoptera* (fleas), order *Coleoptera* (beetles), order *Hemiptera* (bugs), and order *Diptera* (flies and mosquitoes).

Insects impacting poultry include lice, flies, beetles (e.g., darkling or lesser mealworm, discussed in Chapter 16), fleas, mosquitoes, and bugs (e.g., the bloodsucking bedbug) (Table 13.5). Mosquitoes can act as vectors for the spread of diseases. This may be from wild birds to poultry, or to people from animals and birds, known as zoonotic diseases (e.g., West Nile virus).

Fleas attach to the skin of poultry and they feed on blood. Fleas irritate birds in the same way they do mammals. In addition, depending on the extent of the infestation, there can be reduced productivity, blindness, or even death. Examples of fleas that infest poultry are the sticktight flea (*Echidnophaga gallinacea*), which infest chickens and turkeys in tropical and subtropical areas of North America; the western chicken flea or black hen flea (*Ceratophyllus niger*) found on the Pacific coast of North America; and the European chicken flea (*Ceratophyllus gallinae*) found throughout the world.

Lice feed on blood. It is, therefore, not surprising that infestations decrease growth and egg laying in poultry. The most common louse to infest chickens is the chicken body louse (*Menacanthus stramineus*) (see Figure 13.18). There are at least eight other species of lice infesting chickens. In contrast, turkeys can be infested with either or both the large turkey louse (*Chelopistes meleagridis*) and the slender turkey louse (*Oxylipeurus polytrapezius*).

Bed bugs**,** common bed bug (*Cimex lectularius*) and tropical bed bug (*Cimex hemipterus*), are blood sucking insects of which there has been a resurgence. The common bed bug can also be a problem in chicken breeder facilities (see Figure 13.19). Large numbers of

Table 13.5 External parasites of chickens.

	Parasite	Species of Parasite
Insecta	**Bugs (*Hemiptera*)**	
	Common bed bug	*Cimex lectularius*
	Tropical bed bug	*Cimex hemipterus*
	Lice (*Phthiraptera*)	
	Chicken body louse	*Menacanthus stramineus*
	Fleas (*Siphonoptera*)	
Arachnida	**Mites**	
	Chicken or poultry or red mite	*Dermanyssus gallinae*
	Northern fowl mite	*Ornithonyssus sylviarum*
	Scaly leg mites	*Knemidocoptes mutans*
	Ticks	
	Fowl tick	*Argas persicus*

Figure 13.18 Chicken body louse. (*Menacanthus stramineus*) (Photo courtesy of Amy Murillo)

Figure 13.19 Bedbug. (Source: Dan Higgins/Centers for Disease Control)

bed bugs have been found in poultry facilities. These infest chickens, feeding on their blood and causing hens to have anemia (due to blood loss) and, consequently, depressing egg production.

Arachnids

Arachnids include free-living animals such as spiders and the ectoparasites mites and ticks. They are classified as phylum *Arthropoda*, class *Arachnida*. Examples of arachnids affecting poultry are the northern fowl mite (*Ornithonyssus sylviarum*) (Figure 13.20), chicken or red mite (*Dermanyssus gallinae*) (Figure 13.21), tropical fowl mite (*Ornithonyssus bursa*), feather mites, scaly leg mites (*Knemidocoptes mutans*), and depluming mites (*Knemidocoptes gallinae*), together with fowl ticks.

Controlling External Parasites and Bloodsucking Insects

Control procedures include Integrated Pest Management (IPM) and spraying, dusting, and misting with insecticides. The following insecticides can be used in poultry houses: cyromazine (trade name: Larvadex), carbaryl (Sevin), chlorpyrifos (Dursban), coumaphos (Co-Ral), dichlorvos (Vapona), dimethoate (Cygon), fenthion (Baytex), fenvalerate (a pyrethroid) (Ectrin), malathion (Malathion), methomyl (Mairin), naled (Dibrom), permethrin (a pyrethroid) (Ectiban, Atroban), propoxyr (Baygon), and stirofos (Rapon).

13.12 Spread of Infection

Infectious diseases are spread in poultry by the following:

- Contagion from diseased or carrier birds. (This is most important within an individual house or flock.)
- Contagion from other animals (insects, rodents, and free-flying birds; within and between individual

Figure 13.20 Northern fowl mite (*Ornithonys sussylviarum*). (Photo courtesy of Amy Murillo)

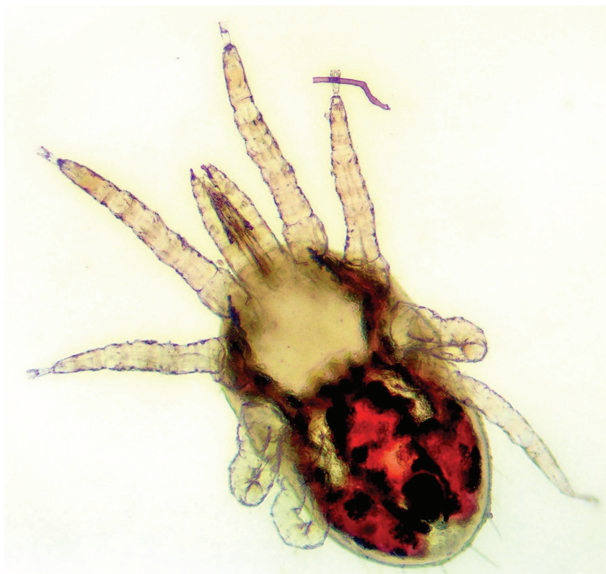


Figure 13.21 Red poultry mite (*Dermanyssus gallinae*). (Source: Martin Pelanek/Shutterstock)

Textbox 13B

A Deeper Dive: Poultry Mites

Northern Fowl Mite

Northern fowl mite (*Ornithonyssus sylviarum*) is considered the "most damaging ectoparasite" of commercial layer chickens in North America (Mullens et al., 2009; see Textbox 13B Figure 1). This blood-sucking, or hematophagous, ectoparasite rapidly spreads in layer houses with increasing intensity. Acaricides are effective in controlling the northern fowl mite where the infestation is relatively light, but not with heavy infestations (Murillo et al., 2016). The number of mites per hen rises during infestations to over 1400 (Vezzoli et al., 2016).

Mite infestation causes inflammation around the cloaca and reduced vent skin temperatures. Infestations with northern fowl mites are accompanied by decreased egg production (numbers ↓ 3%, sizes ↓ 1.35%) and reduced feed conversion efficiency (↓ 5.7%) (Murillo et al., 2016).

Poultry Red Mites

Poultry red mites (*Dermanyssus gallinae*) are blood-sucking ectoparasites that infest birds. These mites are particularly a problem for laying hens. Infestations are commonly found in Asia, Europe, and North America. For instance, it is estimated that 80% of layer flocks in Europe were infested with poultry red mites (Van Emous, 2005). Infestation with poultry red mites is accompanied by losses of blood together with stress. These, in turn, lead to decreased egg production and increased mortality. The costs from these mites in the European Union due to reduced egg production and control measures (acaricide or arachnicide) were calculated at €130 (~US$139) million per year (Van Emous, 2005). Moreover, poultry red mites can impact people directly, causing avian mite dermatitis (gamasoidosis), and can also infest dogs and cats (George et al., 2015).

Textbox 13B Figure 1 A chicken with a substantial infestation of northern fowl mites (*Ornithonyssus sylviarum*). (Photo courtesy of Amy Murillo)

houses or flocks). This is unlikely with good management and pest control measures.

- Airborne. Some microorganisms can be spread in the wind and airflow (within and between individual houses or flocks). Transmission between individual houses or flocks can be very important in localities with heavy poultry populations.
- Contact with contaminated materials (e.g., litter, feed) or objects (crates, feeders, feed bags, and waterers). This is unlikely with good management and disinfection.
- Egg transmission. A number of diseases are transmitted from the hen to the chick through the egg.
- Carcasses of dead birds that have not been disposed of properly.
- Impure water, such as surface drainage water (unlikely with good management and closed water systems).
- Shoes and clothing of people who move from flock to flock (unlikely if biosecurity measures are taken).
- Strategies to prevent pathogenic diseases include:
  - — Biosecurity (see Chapter 16).
  - — Superior animal management.
  - — Vaccination.
  - — Breeding for disease resistance.
  - — Surveillance and monitoring by producers and veterinarians.
  - — Judicious use of antibiotics.

Other Sources of Pathogens

Live-bird markets can represent a source of pathogenic organisms in view of lack of uniform disinfection and the continuous presence of birds as disease reservoirs. Similarly, backyard flocks may represent reservoirs of pathogens. Although illegal in many states, roosters are reared for cockfighting. The unregulated nature of this lends itself to the possibility of being a reservoir for pathogens and a means to transmit poultry diseases via the poultry unit personnel.

13.13 Impact of Other Animals (Beetles, Rodents, and Flies)

Beetles

Beetles are found in the litter of poultry houses. They can have both beneficial and detrimental effects on poultry production. The rove and hister beetles have a beneficial effect, consuming fly eggs and larva. The darkling beetle (*Terebrionidae*) may cause structural damage and/or disease. The larder beetle aids in the decomposition of feathers and such but may damage the facilities. Pesticides can be used to control the population of beetles. Darkling beetles in the litter can serve as a reservoir for pathogens, including *Salmonella* (with consequences for food safety) and viruses (e.g., Marek's disease).

Rodents

Rodents create severe negative consequences for the poultry industry by spreading diseases of poultry, including zoonotic diseases that affect people. Rats and mice are sources and reservoirs of disease-causing microorganisms. The pathogens may be transmitted via the feces or external parasites. The major rodents that infest poultry facilities are brown rats, black rats, and house mice. Rodent populations must be controlled, and the success of these efforts monitored. Approaches include physical exclusion from facilities and feed, rodenticides, and trapping (see Chapter 16).

Flies

The adult fly lays her eggs in wet manure and other damp, rotting matter. From the eggs, the larva or maggot emerges. Larvae grow and develop and ultimately enter the pupa stage. Following metamorphosis, the adult fly leaves the pupal case. Flies can be vectors for the common tapeworm and poultry diseases including Newcastle disease. The problem of flies can be greatly reduced by good management:

- Striving to eliminate sites where maggots can grow and adult flies can feed.
- Frequently cleaning facilities and drying manure.
- Using pesticides (carbamates, organophosphates, and pyrethroids; see above).
- Applying biological control with beneficial insects such as the parasitic wasp or some beetles (rove and hister beetles, particularly in layer houses).

Reducing fly numbers is not only a good-neighbor policy, but it may also reduce diseases in the flock.

Wild Birds

Wild birds are a source of disease-causing microorganisms, including diseases such as West Nile virus (transmitted by mosquitoes and infectious to poultry, wild birds, horses, and people) and highly pathogenic avian influenza (HPAI).

13.14 Immunity and Defenses against Disease

The body has a well-developed defense mechanism that must be understood and utilized in controlling infectious diseases. Immunity is the ability to resist infection. An animal has two types of protective mechanisms: (1) innate or nonspecific immunity, which hinder or prevent invasion of organisms in a nonspecific manner, or (2) adaptive or acquired or specific immunity, which specifically combat agents that invade the body. Other types of immunity include active (humoral/antibodies or cell mediated) or passive (e.g., receiving antibodies from the hen in the yolk and egg white proteins), and naturally acquired or artificially acquired, such as through vaccines.

Innate or Nonspecific Immunity

The innate immune system includes the following:

- Barriers—skin, gastrointestinal mucosa, and the trachea, along with the overlying mucus. These create a barrier that prevents the entry of pathogens, with the mucus "washing out" invading organisms.
- Phagocytosis by heterophils and macrophage (macrophage developing from monocytes).
- Natural killer cells that invade cells infected by viruses.

- Cytokines, including interferons such as:
  — Interferon α (IFNα) antiviral cytokine.
  — Interferon β (IFβ) antiviral cytokine.
  — Interferon γ (IFNγ) antiviral cytokine.
- Host defense peptides (such as defensins).
- Inflammatory responses increasing blood flow. Mast cells release histamine, serotonin, and prostaglandins, which then cause inflammation. In addition, there are proinflammatory cytokine including interleuken (IL)1β.

The avian immune system has been extensively employed in research on immunology. There are two primary lymphoid tissues: (1) the **thymus** (in the neck), where T immune cells originate (T cells being responsible for cell-mediated response to foreign organisms) and (2) the **bursa of Fabricius** (by the cloaca), where B immune cells originate. B cells are responsible for the humoral or antibody-mediated responses to foreign organisms. There is no bursa of Fabricius in mammals. Instead, B cells originate in the bone marrow.

The secondary lymphoid tissues contain both B and T cells and include (1) the spleen (adjacent to the liver), (2) harderian gland (close to the eyeballs), (3) Peyer's patches (at the junction of the jejunum and ileum), (4) cecal tonsils (located close to the junction of the ileum and head of the ceca), (5) Meckel's diverticulum (remnants of the yolk stalk), (6) a diffuse immune system in mucosa (e.g., esophagus, proventriculus, and proctodeum), and possibly also (7) lymph nodes, however, these have not yet been identified in birds.

Definitions

Active immunity: Immunity including antibody production to combat a disease or following vaccination.

Passive immunity: Immunity acquired from another animal, such as the chick from the hen (e.g., antibodies in the yolk).

Artificial immunity: Immunity induced by human intervention.

Antibody: Produced by plasma cells (B immune cells) and binds to an antigen.

Antiserum (sera): Serum containing specific antibodies.

Antigen: Binds to an antibody (most antigens cause the production of antibodies against it).

Immunogen: Evokes or causes the production of antibodies against it.

The purpose of vaccines is to stimulate an active production of antibodies. Active immunity depends upon the production of antibodies, which are glycoproteins (immunoglobulins) in the blood serum and other body fluids. Antibodies are specific for the organism that stimulated their production. Thus, immunity to one disease does not provide immunity to others. All antibodies have the following characteristics: (1) they have at least two binding sites for the antigen, (2) they have two (or multiples of two) heavy chains and two (or multiples of two) light chains, and (3) they have regions in the protein that are constant and regions that are variable, being different for each antibody for a single clone of antibody-producing cells.

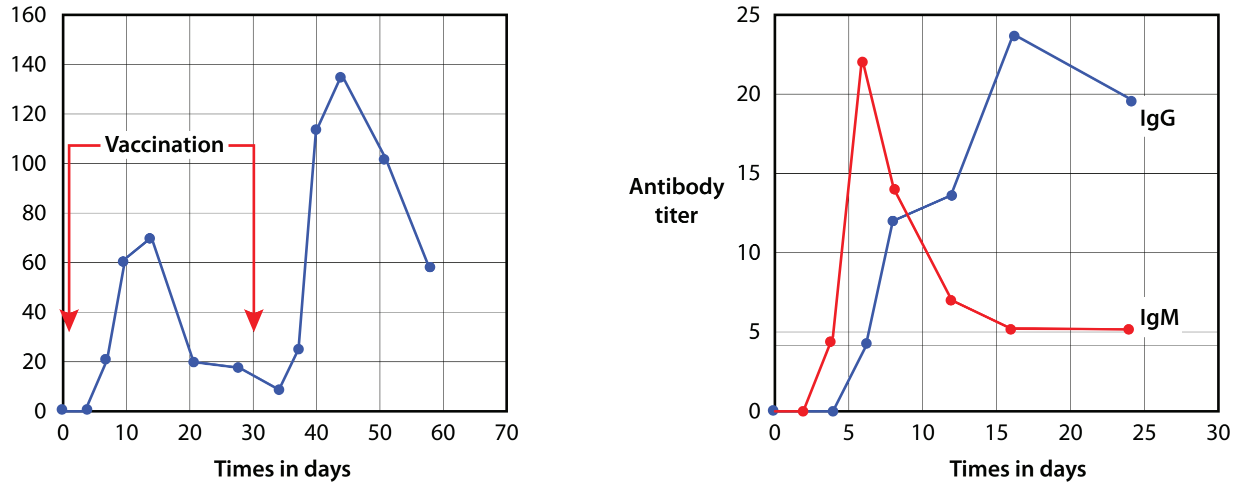
There are five classes or isotypes of immunoglobulins (Ig) (antibodies). These are:

1. **IgM**. This is produced during the early response to an infection or vaccine (see Figure 13.22). It is less specific. It has five multiples of the two heavy and two light chains.
2. **IgY (IgG)**. This is produced during the later response to an infection or vaccine (see Figure 13.22). It is very specific. It has one multiple of the two heavy and two light chains and is the most important antibody in the blood. In birds, IgY is equivalent to immunoglobulin G (IgG) in mammals and the term IgG can be used for birds.
3. **IgD**. An antibody found on the surface of B cells
4. **IgA**. This is found in the intestine with increases following vaccination
5. **IgE**. This is involved in allergies.

Maternally Derived Antibodies (Passive Immunity with Antibodies in the Yolk)

Maternally derived antibodies are passive immunities, with antibodies in the yolk. Embryos, and hence newly hatched chicks, receive IgY antibodies from the yolk sac and IgM and IgA from egg white. Vaccination results in an antibody response in the hen. Antibodies are transferred from the hen to the yolk in the developing ovum in the ovary and in the egg white (for anatomy of the ovary and oviduct see Chapter 4).

There are higher concentrations of antibodies in yolk than in serum. The antibodies are taken up by the embryo from the yolk sac. Maternally derived antibodies protect progeny for between two and three weeks. Passive protection against infection usually lasts no longer than 5 weeks. This is analogous to the transfer of antibodies across the placenta to give newborn babies immunity. In addition, antibodies in cattle are transferred across a calf's intestinal wall from colostrum.



A. Response to initial and booster vaccination against Newcastle Disease Virus.

B. Serum IgG and IgM antibody responses to vaccination against Infectious Bursal Disease Virus.

Figure 13.22 Serum antibody responses to vaccination. (Sources: A based on *Infection and Immunity* 1979, 24: 269–275; B based on *Avian Diseases* 21, 517–521.)

13.15 Infectious Disease Prevention and Control

An effective disease prevention and control program should embrace (1) a flock health program, (2) biosecurity, (3) hatchery management and sanitation, (4) use of disinfectants, (5) use of antibiotics (except in antibiotic-free systems) and coccidiostats (use of ionophores is not permitted in antibiotic free systems), (6) vaccination, (7) the critical role of veterinarians and diagnostic laboratories, and (8) planned responses to disease outbreaks. Specific-Pathogen-Free (SPF) birds may be considered.

Flock Health Program

There are certain basic principles that should always be observed:

- Employ a biosecurity program. Nonessential personnel SHOULD NOT visit poultry units.
- Purchase only day-old chicks or hatching eggs from a source with excellent genetics and poultry health.
- Regulate temperature, humidity, and ventilation during brooding and growing to ensure the comfort of the birds. Prevent overheating, chilling, or buildup of ammonia in the air and moisture in the litter.
- Keep birds separate according to source and age groups. Follow an "all-in, all-out" program.
- Don't crowd birds. Crowding reduces growth and feed efficiency while increasing cannibalism, feather picking, and other stress-related problems.
- Maintain hatchery supply flocks on separate premises from other birds.
- Provide a good commercial feed (or a carefully formulated home-mixed feed).
- Provide an adequate supply of clean, quality water, preferably in a closed system. Monitor water quality for bacteria, particularly coliform, and other contamination (minerals that adversely affect poultry such as nitrates, zinc, and sodium). Smaller-scale producers should avoid watering from surface tanks, streams, or ponds.
- Develop the vaccination program in consultation with a poultry veterinarian.
- Control internal and external parasites.
- Control vermin and screen out free-flying birds.
- If a disease problem develops, obtain an early veterinary diagnosis and apply the best treatment and eradication measures.
- Dispose of all dead birds as follows: incineration, composting, or pit or deep burial.

- Maintain good records relative to flock health including vaccination history, disease problems, and medication employed.
- Avoid keeping chickens and turkeys on the same premises.

Definitions

Anemia: A lack of blood (specifically red blood cells and hemoglobin).

Exudate: A fluid oozing from a tissue.

Hemorrhage or bleeding: When blood leaves a ruptured blood vessel.

Lesion: A visible change (color, size, or shape) within a tissue due to a disease.

Biosecurity

Biosecurity programs are developed on an individual farm or company basis in an attempt to prevent transmission of diseases by people (biosecurity is discussed in detail in Chapter 16). The programs always involve carefully thought-out standard operating procedures (SOPs); training programs for workers, visitors, and service people; execution of SOPs; and monitoring and policing. The operating procedures involve use of coveralls, boots, head coverings, disinfectants, and so on. There may be shower-in, shower-out, and/or disposable shoe and head coverings. Vehicles may also need to be subjected to intense washing. Personal hygiene is a must. Service personnel (deliveries of feed, supplies, transportation of birds or eggs to the processor, dead bird pickup, etc.) should be restricted to specific areas on the poultry unit.

Hatchery Management and Sanitation

Hatching eggs should be collected at frequent intervals using the following practices. (1) Use clean and disinfected containers to collect the eggs and prevent contamination from organisms on hands or clothing. (2) Maintain the identity of all eggs relative to the breeder flocks of origin. (3) Do not use dirty eggs for hatching. (4) Collect dirty eggs in a separate container from hatching eggs and clean. (5) Store eggs in a cool place in properly cleaned and disinfected racks following fumigation. (6) Hold the storage period to as short a time as possible before setting. (7) Use new or fumigated cases to transport eggs to the hatchery. (8) Burn soiled egg case fillers.

An effective program for the control of infections includes the following. (1) Arrange the hatchery building with separate rooms each with separate ventilation for egg receiving, incubation and hatching, chick holding, and disposal of shells/membranes/dead embryos, plus cleaning of trays. (2) Use biosecurity with admission permitted only to authorized personnel who have taken proper precautions (e.g., shower-in, shower-out). (3) Clean thoroughly and disinfect frequently. (4) Incinerate all hatchery waste. (5) Clean thoroughly, then fumigate the hatching compartment of incubators, including hatching trays, after each hatch. (6) Transport day-old chicks and poults in clean, new boxes or in disinfected plastic cartons. After each use, clean and disinfect all crates and vehicles used for transporting started or adult birds. (7) Maintain the identity of all chicks and poults relative to the breeder flock of origin. (8) Avoid mixing the progeny of different breeder flocks.

Cleaning and Disinfecting

In poultry houses, cleaning and disinfecting should include the removal of all litter and droppings. Scrub the walls, floors, and equipment with hot water containing detergent and then rinse. Spray with a suitable disinfectant, following the manufacturer's directions. In hatcheries, cleaning and disinfecting should include the removal of trays, fans, and so forth for separate cleaning. Thoroughly clean the ceiling, walls, and floors. Rinse and then replace the cleaned fans, trays, etc. Bring the incubator to the normal operating temperature and fumigate the hatchery before inserting eggs. If eggs are hatching and incubating in the same machine, clean the entire machine after each hatch.

Disinfectants

Disinfectants are chemicals that kill bacteria (bactericidal activity) and protozoa along with destroying viruses, molds, and the transmittable forms of internal parasites. Cleaning and disinfection become extremely important in breaking the cycle of infection-reinfection. Also, in the case of a disease outbreak and depopulation, the premises must be disinfected. Thorough cleaning should precede disinfection. Organic matter can protect microorganisms. Heat (steam, hot water, etc.) is an effective disinfectant. In addition, a chemical disinfectant is used. A good chemical disinfectant should kill pathogenic microorganisms, remain stable in and penetrate organic matter rapidly, dissolve in water and remain in solution, be nontoxic to birds and humans, and be economical to use. There are a large number of available disinfectants, each with usefulness and possible limitations. When using a disinfectant, always follow the manufacturer's directions.

13.16 Vaccination

Table 13.6 lists some of the major poultry vaccines. Vaccination is the injection of some agent (vaccine) into an animal to develop a competent immune response and hence prevent disease. Vaccines contain large numbers of the disease-causing organism (either live but nonpathogenic/nonvirulent or killed) or potential surface proteins. Most poultry vaccines are of the live-virus type, produced by growing laboratory strains of virus in embryonated chicken eggs or in cell culture systems. Bacterial vaccines, called bacterins, are killed or inactivated preparations of bacteria, produced by growing selected strains of bacterial organisms in artificial media.

Interesting Factoid

The word "vaccine" is derived from the Latin words for cow (*vacca*) and "from cows" (*vaccinus*). The first vaccine used cow pox to induce immunity to small pox in humans. It was developed by Edward Jenner around 1800.

So-called vaccination outbreaks do occur. The factors that influence vaccine-response in poultry are many, mainly depending on the host and environment. Ordinarily, some protective immunity is conferred when birds are vaccinated, although the vaccine within itself cannot guarantee it. A sound vaccination program is part of a good management program, but not a substitute for a sanitation program.

Diseases for Which Vaccines Are Available

Viral diseases that can be controlled by vaccination include avian encephalomyelitis (epidemic tremors), fowlpox, infectious bursal disease (Gumboro), infectious bronchitis, laryngotracheitis, Marek's disease, and Newcastle disease. Bacterins available commercially include erysipelas bacterin, fowl cholera bacterin, and mixed bacterins.

Vaccination Programs for Chickens and Turkeys

In a concentrated poultry area, various diseases are a constant threat to the producer's revenue. Vaccination is cheap insurance against heavy losses from some of

Table 13.6 Examples of vaccinations for poultry.

Disease/Bacteria	Broiler Chickens	Broiler Breeders	Layers	Turkeys	Turkey Breeders	Ducks
Anatipestifer disease						X
Chicken infectious anemia		X				
Coccidiosis	X?					
Duck virus enteritis						X
Duck viral hepatitis						X
Encephalomyelitis		X	X		X	
Erysipelas					X	
Fowl cholera		X		X	X	X?
Fowlpox		X	X			
Hemorrhagic enteritis				X	X	
Infectious bronchitis	X	X	X			
Infectious bursal disease	X	X	X			
Laryngotracheitis or infectious Laryngotracheitis		X	X			
Marek's disease	X	X	X			
Mycoplasma gallisepticum			X			
Newcastle Disease	X	X	X	X	X	
Tenosynovitis		X				

these diseases. Vaccinate chickens, turkeys, and other poultry only after getting expert advice from a poultry veterinarian or following integrator requirements.

In **broiler production**, chickens are vaccinated against the following:

- Marek's disease caused by the Marek's disease virus (MDV) or Gallid herpesvirus 2 (GaHV-2).
- Newcastle disease caused by Newcastle disease virus (NDV).
- Infectious bronchitis caused by the infectious bronchitis virus (IBV).
- Infectious bursal disease (also known as IBD, Gumboro disease, infectious bursitis, and infectious avian nephrosis; caused by the infectious bursal disease virus (IBDV).

In the United States, hatcheries for broiler chicks employ *in ovo* vaccination at 17–19 days of incubation. Alternatively, vaccination is performed in day-old chicks.

Layer chickens are vaccinated against encephalomyelitis, fowlpox, infectious bronchitis, infectious bursal disease, laryngotracheitis, Marek's disease, *Mycoplasma gallisepticum*, and Newcastle disease. **Broiler breeders** are vaccinated against chicken infectious anemia, encephalomyelitis, fowl cholera, fowlpox, infectious bronchitis, infectious bursal disease, laryngotracheitis, Marek's disease, Newcastle disease, and tenosynovitis.

Turkeys are vaccinated against fowl cholera, hemorrhagic enteritis, and Newcastle disease. **Turkey breeders** are vaccinated against encephalomyelitis, erysipelas, fowl cholera, hemorrhagic enteritis, and Newcastle disease. Vaccines are also used to combat coccidiosis (vaccines against the protozoan *Eimeria*).

13.17 Role of Veterinarians and Diagnostic Laboratories

Large integrators have poultry veterinarians and pathology laboratories. Small and medium producers may hire a consulting veterinarian with poultry expertise. Diagnostic laboratories (commercial or state-operated at a fee) are available to producers. Accurate identification of poultry diseases is essential for treatment. A wrong diagnosis can result in depopulation when not required or improper medication. These can be costly. When a disease outbreak is suspected, live birds showing typical symptoms should be immediately submitted to a poultry diagnostic laboratory for examination. Such laboratories are equipped to identify the disease problem and make recommendations for control. Practicing veterinarians, industry service people, and trained extension personnel working with producers and a diagnostic laboratory can bring about a reduction in losses due to disease.

Treatment of Disease Outbreaks

Treatment of disease should be initiated only after a reliable diagnosis from a poultry veterinarian assisted by a poultry diagnostic laboratory. Diseases can be treated by allowing them to run their course, culling sick birds, depopulation of the house or facility, or administering drugs. Misdiagnosis can result in considerable losses. Drugs should normally be used according to the instructions on the label and may produce toxic effects if used improperly.

13.18 Antibiotics

Prescription Antibiotics and Judicious Use of Antibiotics

In the United States, the Food and Drug Administration requires that there be a valid veterinarian-client-patient relationship before an antibiotic is used as a growth promotant and not in accordance to label direction. However, veterinarians in integrated poultry production systems are generally averse to using antibiotics in an extralabel manner.

It is advisable that prescription antibiotics are used with the minimal number of diseased birds and those in contact with them (i.e., the same house). The latter is to prevent secondary infection while reducing the cost of treatment and also minimizing environmental contamination and the risks of antibiotic resistance. The concept of the judicious use of antibiotics comes from an American Veterinary Medical Association (AVMA) initiative.

13.19 Specific-Pathogen-Free (SPF) Programs

The Specific-Pathogen-Free (SPF) program is a combination of breeding, testing, sanitation, and management practices designed to establish and maintain breeder flocks free of specific known infectious diseases. This program is directed toward eggs produced for vaccine production. An SPF program uses regularly cleaned and disinfected caged birds in locked rooms constructed to exclude vermin and wild birds. Feed (medicated with coccidiostat) should be in bulk-feed facilities with outside filler pipes. Facilities must be at least 100 ft (30 m) from public highways and at least 1,000 ft (300 m) from other poultry houses on adjacent premises. Shoe covers should be available. All units must have a footbath with an approved disinfectant (changed daily) and a stiff brush next to the door in the entry room. All personnel must wear covers and clean their footwear upon entering or leaving. Only pullorum- and typhoid-free day-old chicks should be received, arriving directly from the hatchery in new or disinfected shipping equipment. Workers should shower-in, shower-out, and not visit the premises where other poultry are kept or poultry products are processed, or have pet birds. Maintain good records. If birds become positive for diseases, depopulate the facility immediately, disposing of carcasses by incineration.

Genetic Resistance to Disease

Selected lines of chickens have been found to vary in their resistance and susceptibility to various diseases. Thus, genetics shows promise in reducing the impact of diseases. Genomics will allow identification of the genes responsible for disease resistance and these can then be introgressed by primary breeders.

13.20 Metabolic Diseases

Pulmonary Arterial Hypertension (PAH) Syndrome

Ascites, or pulmonary arterial hypertension (high blood pressure in the lung) syndrome, causes increased mortality, elevated pulmonary arterial blood pressure, lower oxygen partial pressures in the hemoglobin in the red blood cells, reduced oxygen and carbon dioxide transfer in the lungs, increased partial pressures of carbon dioxide in the blood, and accumulation of serous fluid (serum or lymph like fluid) in the abdominal cavity. Ascites reduces livability by contributing to mortalities in apparently healthy flocks and significantly to live-bird condemnations (culls).

Environment can induce ascites (e.g., low atmospheric pressure/oxygen availability at high altitudes and cold stress). Other predisposing factors are aspergillosis and reduced oxygen-carrying capacity of the blood due to carbon monoxide. Predisposition for ascites is genetic. Rapidly growing broiler chickens may not be able to supply the oxygen needs of tissues, and there may be a defect in the mitochondria.

Bone Diseases

Leg Weakness and Tibial Dyschondroplasia

Leg weakness profoundly affects broiler chickens and turkeys, leading to splaying of the legs, poor performance, and on-farm condemnations. Leg weakness or tibial dyschondroplasia is a disease of the long bone (the tibia). The growth plate fails to calcify in the cartilage (transitional zone). Tibial dyschondroplasia is particularly found in fast-growing broiler chickens. This disease leads to loss of mobility, lack of access to feed and water, and is associated with very poor performance. Results of research with addition of the metabolite of vitamin D (25-hydroxyvitamin D_3) to the feed are promising. Experimentally, tibial dyschondroplasia can be induced by a low calcium diet, and this can be overcome with 25-hydroxyvitamin D_3.

Caged Layer Fatigue, Osteoporosis, and Bone Fracturing

With the calcium demands of egg production, it is not surprising that laying hens can show abnormalities of bones. Associated with caged layer fatigue are the symptoms of osteoporosis. Namely, bones become more porous but brittle, bend under pressure (e.g., the ribs), and also have the tendency to break. Fracture of fragile limbs, bones, and ribs can lead ultimately to death. Bone fracture can also occur prior to death during transportation to a processor or during processing. Moreover, the fracturing of the bones leads to problems of processing old or spent hens.

Muscle Diseases and Myopathy

Muscle myopathy is observed in poultry causing a marked reduction in meat quality and performance. There are multiple breast muscle myopathies. Breast muscle myopathies cause the downgrading of carcasses, condemnations of carcasses, and consumer resistance to chicken. All of these lead to economic losses.

An example of a breast muscle myopathy is **deep pectoral myopathy** or green muscle disease. This is found in both chickens and turkeys. There is local bleeding and tissue death followed by breakdown of the hemoglobin to yield a green color. Two other breast muscle myopathies (**white striping** and **woody breast**) affect the pectoralis major muscle within chickens. In both there is localized muscle degeneration.

White Striping Condition

The white striping condition is characterized by localized muscle fiber degeneration with replacement by connective tissue. There are white striations that run parallel to muscle fibers in breast muscles. The white striping condition is seen in about 25% of broiler chickens.

TEXTBOX 13C

A Deeper Dive: Backyard Chickens and Poultry Diseases

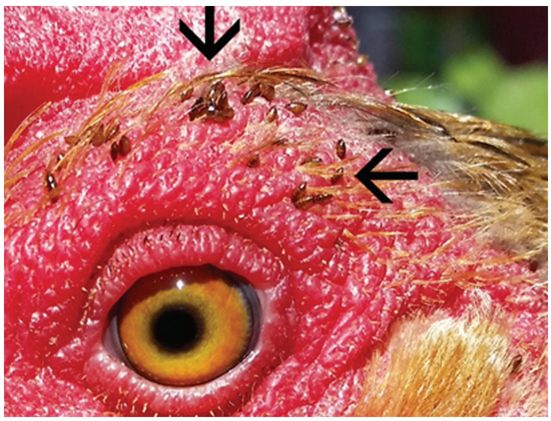
Backyard chickens are growing in popularity (see Textbox 3F). In rural areas, it is estimated that 6.5% of residences in the Southern United States have poultry flocks—chickens and game birds (Garber et al., 2007). This is similar to the estimate of 4% of single-family homes on 1 acre (0.40 hectare) or more owning chickens in four metropolitan regions (USDA, 2013). There have been increases in the number of people in US urban and suburban areas with backyard chickens (Linares and Nixon, 2011).

The United States Department of Agriculture reports that about 1% of households have chickens in four cities, Denver, Los Angeles, Miami, and New York City (2013) with 4% planning to have chickens. This urban ownership of chickens is said to be related to chickens being "likable" and their providing eggs (Linares and Nixon, 2011). This can be part of the "eat local" movement (Linares and Nixon, 2011; Blecha and Leitner, 2013.) with the eggs perceived as more healthy and nutritious (United States Department of Agriculture, 2013).

Necropsy of laying hens from backyard flocks in Finland indicate that 27% have Marek's disease (Pohjola et al., 2015). In a survey of owners of backyard flocks in Finland, only 13% used different shoes in the poultry areas and only 35% could wash their hands before leaving the poultry areas (Pohjola et al., 2015). Survey research indicates that owners of backyard flocks in Greater London show an absence of disease control practices, including vaccination and biosecurity (Karabozhilova et al., 2012). Similarly, based on a survey of owners of backyard chickens in the US, there is little attention to disease control with 61% not vaccinating against Marek's disease (Elkhoraibi et al., 2014). Moreover, many do not use coccidiosis preventatives or dewormers (Elkhoraibi et al., 2014). Problems with backyard chickens include the following:

- Biosecurity.
  - The birds are in contact with wild birds with the possibility of exchange of pathogens.
  - Backyard chickens can be a reservoir of avian pathogens, potentially highly pathogenic avian influenza and parasites.
  - Owners of backyard chickens and their vehicles can spread poultry diseases to commercial poultry.
- Inadequate programs for poultry health.
  - Lack of vaccination, with Marek's disease being a major cause of mortalities (Mete et al., 2013).
  - Inadequate control of parasites (also see below).
  - Inadequate veterinary care.
- The risk of spread of zoonotic diseases (e.g., salmonellosis and campylobacteriosis) to the owners and their families and hence to the community. Research, however, indicates that "backyard chickens do not seem to pose a major risk to public health" (Mete et al., 2013).
- Inadequate animal welfare due to predators including foxes, raccoons, and coyotes; cannibalism due to lack of beak trimming; poor nutrition; increased disease with mortalities frequently due to infectious diseases (Mete et al., 2013; Pohjola et al., 2014); and effects of adverse weather.
- Regulation, ordinances, impact on neighbors (noise from roosters, odor, flies, rodents, and attracting predators that can attack dogs, cats and, potentially, children), and oversight (Linares and Nixon, 2011; Noll et al., 2012). The issue of biosecurity with backyard flocks is accentuated by there being an average of 1.9 backyard flocks within a mile radius of commercial poultry operations (Garber et al., 2007).

About 80% of backyard chicken flocks in California were found to be infested with a diversity of ectoparasites, with one species of lice, the chicken body louse (*Menacanthus stramineus*), being found in 50% of flocks (Murillo and Mullens, 2016). Other species of lice were also observed, including the poultry fluff louse (*Goniocotes gallinae*; 35%) and feather or wing louse (*Lipeurus caponis*; 20%). Ectoparasite infestations also included sticktight flea (or hen flea or tickfast flea; *Echidnophaga gallinacean*; 20%), with some severe infestations (see Textbox 13C Figure 1); northern fowl mite (*Ornithonyssus sylviarum*; 15%); scaly leg mite (*Knemidocoptes mutans*; 10%), with some very severe infestations; and poultry red mite (*Dermanyssus gallinae*; 5%) (Murillo and Mullens, 2016).



Textbox 13C Figure 1 Multiple sticktight fleas infesting the area between the comb and the eye. (Photo courtesy of Amy Murillo)

Woody Breast Condition

Woody breast is seen in heavy and medium-sized birds. In the condition, parts of the breast muscle are hard and rigid to the touch. There is degeneration and/or swelling and/or fragmentation of myofibers with replacement by connective and adipose tissue. There can be an exudate of a thick fluid and at worst hemorrhaging on the muscle surface. The woody breast condition is seen in over 5% of broiler chickens.

Reproductive Diseases

The laying hen can become infertile or die due to diseases of the reproductive tract. This includes the following:

- Salpingitis—the oviduct becomes filled (engorged) with yolk and possibly egg white.
- Egg bound—the calcified egg is retained in the oviduct.
- Peritonitis following internal ovulation into the abdominal cavity followed by inflammation.

There can also be secondary bacterial infection.

13.21 Environmental Stress

Heat Stress

High environmental temperatures have been associated with mortalities in broiler chickens. Although this has been greatly improved with tunnel ventilation, growth rates and feed efficiency are reduced in the hottest months of the year. In laying hens, heat stress is associated with reduced egg production, reduced egg weight, and reduced shell weight.

Cold Stress

Cold stress impairs performance of fast-growing broiler chicks. Moreover, it may lead to ascites.

Low Atmospheric Pressure

At high altitudes, fast-growing broiler chickens are more susceptible to ascites. Experimentally, ascites can be induced by low oxygen pressure, for example, in hypobaric chambers (i.e., with low atmospheric pressure).

13.22 Behavioral Problems

Cannibalism/Persecution

Cannibalism/persecution can take multiple forms:

- Vent picking (or the area below the vent) is a very severe form of cannibalism that is found in laying hens.
- Toe picking is most commonly seen in chicks or young game birds.
- Head picking usually follows injuries to the comb or wattles caused by freezing or by fighting between males.
- Blueback is caused by feather picking in turkeys, followed by exposure to sunlight. Blueback may result from overcrowding in the brooder, keeping the poults on the sunporch too long, and lack of sufficient fiber in the ration.
- Egg eating is costly but can be reduced by beak trimming.

Hysteria/Fright

Excessive fright can be observed in growing pullets or layers. With floor-housed birds, there is flight and piling up in the corners of the house, resulting in suffocation. Caged layers may attempt to fly, resulting in injuries to wings and legs. Care should be taken not to frighten birds. The Poultry Improvement Plan in the United States is covered in Appendix II.

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14

Food Safety

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Know the categories of agents that impact food safety.
2. Understand the impact of foodborne pathogens globally and in the United States.
3. List the major pathogens related to food safety issues in poultry.
4. List the major government agencies regulating the safety of food in the United States.
5. Know how *Salmonella enteritidis* is being combated in eggs in the United States.
6. Define HACCP.
7. Know how poultry processors reduce pathogens.
8. Know if there are food safety issues with eating poultry in restaurant. If yes, why?
9. Know if storage temperature for poultry and eggs is important.
10. Understand the problem with cross contamination, particularly with raw poultry to ready to eat items.
11. Know what pasteurization of eggs is and why it is done.
12. Give recommendations on how consumers should store, handle, and cook eggs and poultry meat.
13. Know how allergens in food can impact people.
14. Know what the impacts are of contamination of foods contaminated with chemicals, pesticides, and adulterants?
15. Understand how irradiation improves food safety and why it is not used.

14.1 Introduction

Food is essential to human life but also can represent causes of diseases and even death. The causative agents of disease in food include pathogens (bacteria, viruses, and fungi) and parasites (single-celled parasites together with nematode and other worms and flukes); toxins and other chemicals such as arsenic, nitrate, and pesticides; and allergens. In addition, food may be adulterated with foreign materials such as metals or glass—this occurring post harvesting or during manufacture. Globally, foods such as undercooked meat, eggs, and dairy products along with uncooked vegetables are the sources of multiple pathogens including norovirus, *Campylobacter*, non-typhoidal *Salmonella*, and pathogenic *E. coli*, and hence, much disease.

14.2 Impact of Foodborne Diseases

In 2015, the World Health Organization (WHO) estimated that foodborne diseases annually caused 600 million people to become ill, 420,000 deaths (230,000 deaths from diarrhoeal diseases), and 125,000 deaths of children under 5 years old.

Codex Alimentarius

The *Codex Alimentarius* or "Food Code" is a global collection of standards, guidelines, and codes of practice. These are collected under the auspices of the Codex Alimentarius Commission; this being under the Food and Agriculture Organization (FAO) and the World Health Organization (WHO) of the United Nations.

While foodborne diseases are disproportionately found in developing countries, they are still a danger in developed countries. It is estimated that there are about 10 million foodborne illnesses per year in the United States. Where the product containing the infective agent can be identified, poultry and eggs are frequently the cause (see Textbox 14A for more details).

Policy makers, farmers, food processors, restaurants, and consumers have long recognized the importance of food safety from farm to fork. Regulations are in place and stringently enforced. Where problems have arisen, there are recalls of food items in the United States (see Textbox 14B) and elsewhere. In the case of the latter, a British supermarket was required to withdraw pasta in 2017 because it wasn't correctly labeled for containing eggs. There have also been major outbreaks in Western Europe of *Salmonella enteriditis* in eggs.

Textbox 14B

Examples of Recalls of Poultry and Eggs in the United States

In 2015, there were 33 recalls of poultry and egg products by the USDA's Food Safety and Inspection Service (FSIS) for reasons including *Listeria monocytogenes*, *Salmonella*, and undeclared allergens. In 2016, there were 39 recalls of poultry and egg products for reasons including *Listeria monocytogenes*, *E. coli*, undeclared allergens, and processing defects. In 2017, examples of recalls include (1) chicken salad products possibly adulterated with *Listeria monocytogenes*, (2) chicken sausage products containing monosodium glutamate (MSG) that were not labeled correctly, (3) breaded chicken products contaminated with metals, (4) ostrich jerky products misbranded and with undeclared allergens, and (5) breaded chicken products with possible foreign matter contamination.

In 2015, there were two separate outbreaks of *Salmonella enteritidis* infections that were linked to raw, frozen, stuffed chicken entrees. There was then a recall of these products. In 2016, there was a multi-state outbreak of *Salmonella oranienburg* in three US states that resulted in a recall of eggs.

There have been, however, significant outbreaks of foodborne diseases in North America (see Table 14.1). Previous major outbreaks include *Escherichia coli* 0157:H7 in undercooked beef, unpasteurized apple cider and raw vegetables, and *Salmonella typhimurium* in poultry meat.

Textbox 14A

A Deeper Dive: Poultry and Eggs Causing Foodborne Disease

According to the Centers for Disease Control (2018), there are over 9 million cases of foodborne diseases in the USA from known pathogens. These result in over a thousand deaths per year. Consumption of poultry and eggs cause over a quarter of the illnesses and a third of the deaths (Painter et al., 2013).

Excluding the situation where the food was undetermined, poultry and eggs were the cause of 45% of deaths. The responsible agents for foodborne diseases from poultry and eggs in the US are predominantly bacterial but with significant numbers being viral in origin.

- Illness
  - Poultry: 1.5 million are bacterial and 0.6 million are viral per year.
  - Eggs: 0.2 million are bacterial and 0.4 million are viral per year.
- Hospitalizations
  - Poultry: 11,029 are bacterial and 1,604 are viral per year.
  - Eggs: 2,979 are bacterial and 1,041 are viral per year.
- Deaths
  - Poultry: 393 are bacterial and 16 are viral per year.
  - Eggs: 57 are bacterial and 11 are viral per year.

Table 14.1 Major foodborne diseases and their impact in the US.

Pathogen	Million Illnesses per Year	Percentage Foodborne	Hospitalizations	Deaths
Bacteria				
Campylobacter spp.	1.06	80	13,240	119
Foodborne *Clostridium perfringens*	0.97	100	1,520	266
Foodborne *Staphylococcus aureus*	0.24	100	1,067	6
Non-typhoidal *Salmonella* spp.	1.09	94	23,128	452
Single-celled parasites				
Cryptosporidium spp.	0.68	8	2,795	46
Giardia intestinalis	1.12	7	3,581	34
Toxoplasma gondii	0.17	50	8,889	656
Viruses				
Norovirus	20.8	26	69,721	571

Data from the CDC.

There is a growing realization that the issue of food safety is still vitally important. Foodborne pathogens give rise to diseases that range in severity from diarrhea to life-threatening situations requiring hospitalization and even leading to death. The US Centers for Disease Control (CDC) estimates that foodborne pathogens in the United States lead to about 48 million illnesses, 128,000 hospitalizations, and 3,000 human deaths each year. Many of these foodborne illnesses are the result of animal products. Pathogens associated with poultry and eggs include:

- *Listeria monocytogenes* (often contaminating poultry during processing with a reservoir for *Listeria* being in the drains)
- *Campylobacter jejuni*
- *Salmonella* species such as:
  - *Salmonella* serotype *Enteriditis* (most frequently associated with eggs—see later in the chapter).
  - *Salmonella* serotype *Typhimurium* (the most commonly isolated serotype, which can colonize the crop of broiler chickens and contaminate chicken meat).

Most at risk from foodborne disease are people whose immune systems are not functioning adequately (immune-compromised), such as the elderly, young children, people receiving chemotherapy or immune-suppressive drugs, and individuals infected with human immunodeficiency virus (HIV).

14.3 Government and Food Safety

Most countries have consumer education programs about food safety and rigorously enforce regulations, together with regulatory agencies that police the enforcement of regulations. Some countries have moved to a single department with responsibility for food safety (e.g., the United Kingdom). In others, like the United States, there are several independent agencies of the federal government with responsibility for food safety. These include USDA's FSIS, USDA's Animal and Plant Health Inspection Service (APHIS), the Food and Drug Administration (FDA), and the CDC.

In the US, poultry and other meats are inspected by the FSIS. In contrast, eggs are subject to regulations and inspection from two agencies, the FDA and the USDA. The USDA oversees grading as well as egg breaking and the pasteurization of liquid eggs and egg products. The FDA oversees labeling and food safety of shell eggs.

Food safety is under different agencies in different counties. Examples include: the Ministry of Agriculture (Brazil), Health Canada and the Canadian Food Inspection Agency (Canada), China Food and Drug Administration (China), European Food Safety Authority (European Union), Food Safety and Standards Authority of India under the Ministry of Health and Family Welfare (India), and the Food Standards Agency (United Kingdom).

14.4 Pathogens and Food Safety

Food contains microorganisms or has them on its surface, particularly when sealed packages are left open. Most microorganisms in food are benign (although they may cause spoilage of food). Some are pathogenic, that is, they can cause human or animal diseases. These pathogens include bacteria and viruses together with the less common single-celled parasites. Pathogens and other microorganisms can be introduced into foods, as purchased from grocery stores, in the following manner:

- **During production on the farm**. Poultry can acquire foodborne pathogens such as *Campylobacter*, *Clostridia*, *E. coli*, and *Salmonella* in their feed. There is a need to control *Salmonella* during feed processing. The numbers of pathogens can be reduced by feed additives such as formic acid or sodium formate. Vaccination can provide protection against *Salmonella typhimurium*, *Salmonella enteritidis*, and *Salmonella* Heidelberg; reducing colonization by *Salmonella* in chickens and turkeys.
- **During transportation**. For example, *Campylobacter* can be spread in broiler transporter coops.
- **During processing**. For example, from inadequate sanitation of the equipment and from the drains.

Moreover, pathogens can be introduced into the food via other routes, like employees transferring pathogens to food due to poor practices (e.g., lack of hand washing, inadequate sanitation of surfaces, etc.) or meat juices contaminating ready-to-eat items and inattention to correct temperatures for storage and cooking. These things can happen at the grocery store, at the consumer's home, in restaurant kitchens, and at community events (e.g., family or office picnics and church potluck meals).

Infectious Dose of Pathogens

The infectious dose of a specific pathogen is the approximate number of pathogenic organisms required to cause a disease. The infectious dose varies between people and their immune systems. The infectious doses for pathogens in poultry meat or eggs are the following:

- *Salmonella enterica* serotype *enteritidis* (SE) and *Salmonella* serotype *Typhimurium* (ST): 1000 bacilli (see Figure 14.1).
- *Campylobacter jejuni*: 400–500 bacilli (see Figure 14.2).
- *Listeria monocytogenes*:10–100 million bacilli (but 0.1–10 million in immune-compromised people).

Figure 14.1 A scanning electron microscopic (SEM) image of *Salmonella* sp. bacteria has invaded a higher vertebrate cell. (Source: Centers for Disease Control).

Figure 14.2 Three-dimensional (3D) computer-generated image of *Campylobacter* bacteria based on scanning electron microscopy (SEM) (digitally-colored mauve). (Source: Centers for Disease Control)

If food is prepared correctly (which usually involves adequate cooking) the vast majority of the microorganisms will be killed or removed. Microorganisms in food multiply rapidly at warm temperatures and in an environment with plentiful nutrients for bacterial growth. The danger zone is between 40° and 140°F (4.5°–60°C), with the rate of bacterial growth becoming higher as temperatures rise.

Salmonella and Poultry and Eggs

Globally, the bacterium *Salmonella* is the cause of much disease. This includes typhoid fever caused by *Salmonella typhi* (more accurately *Salmonella enterica* serotype *Typhi*) together with nontyphoidal *Salmonella*. Between 12 hours and 3 days after initial exposure to the bacterium, people infected with nontyphoidal *Salmonella* can develop symptoms including diarrhea, fever, and abdominal cramps. Almost 600 different *Salmonella* serotypes cause illnesses in the US and the CDC considers nontyphoidal *Salmonella* to be a threat to public health. Among the most important are *Salmonella enterica* serotype *Enteritidis* (SE) and *Salmonella* serotype *Typhimurium* (ST).

TEXTBOX 14C

A Deeper Dive: *Salmonella* in the United States

National *Salmonella* Surveillance in USA

While the incidence of SE decreased from 3.5 SE isolates per 100,000 people in 1996 to 1.7 SE isolates per 100,000 people in 2003, there was a subsequent increase to 2.1 SE isolates per 100,000 people in 2007 and then 2.4 SE isolates per 100,000 people in 2011.

***Salmonella* serotype Typhimurium (ST)**

Prevalence of ST in the United States has steadily decreased from 3.6 ST isolates per 100,000 people in 1996 to 2.4 ST isolates per 100,000 people in 2011 (Boore et al., 2015).

Listeria and Food Safety

Another bacterium responsible for foodborne disease is *Listeria monocytogenes*. Contamination with *Listeria monocytogenes*is a problem with chicken and turkey meat/products. People eating food contaminated with this pathogen can develop listeriosis. This is an unusual but potentially very serious or fatal disease with symptoms such as fever and severe headache. It can also cause miscarriages (spontaneous abortion) or be fatal. As mentioned above, serious illness or death is particularly a problem with the elderly, young children, and those with immune impairment, such as those undergoing chemotherapy or having HIV. The FSIS has recalled chicken and turkey products due to contamination with *Listeria monocytogenes* on multiple occasions. This leads to major financial losses to processors and reduces public confidence in poultry.

Campylobacter and Food Safety

Another bacterium responsible for foodborne disease is *Campylobacter jejuni*. This can contaminate poultry and cause foodborne disease. The symptoms of *Campylobacter jejuni* infection or campylobacteriosis are delayed after exposure, beginning 2 to 5 days later. Symptoms include diarrhea (potentially bloody), cramping, fever, and possibly nausea and vomiting.

14.5 Food Safety Aspects of Eggs

Introduction

Salmonella, specifically SE, has been a major cause of bacterial foodborne disease, with shell eggs the most important source. Eggs laid by hens carrying SE can contain SE in the yolk due to the presence of SE in the ovary. *Salmonella* has been isolated from the ceca of most old hens (between 24–65% in different flocks). It is not surprising that the surface of eggs may be contaminated with *Salmonella* and other bacteria. Thus, Grade A eggs must be sold washed and disinfected. The CDC concluded that eggs are the predominant source of SE infections, with uncooked or undercooked eggs being a particular threat to public health. The goal of FDA regulations is to prevent SE contamination of shell eggs on farms and subsequent growth during storage and transportation.

Handling of Eggs

To prevent illness from bacteria in eggs, keep eggs refrigerated, cook eggs until yolks are firm, and thoroughly cook foods containing eggs.

Pasteurization

In the US, liquid or broken eggs are used widely in the food industry as an ingredient for many products. This represents about 30% of eggs used in the

US. Liquid eggs, together with powdered eggs, are subjected to pasteurization. This entails rapid heating and cooling in a process analogous to that with milk. Pasteurization of whole eggs is performed by heating to 60°C (140°F) for 3.5 minutes. The yolk has to reach a temperature of 58.9°C (138°F). Responsibility for inspection and food safety of eggs is under the auspices of the FDA. Pasteurization has been a legal requirement in the United States for egg products since 1970.

The FDA's Egg Rule

In 2014, the FDA announced a regulation (the "Egg Rule") to eliminate *Salmonella enteritis* (SE) in eggs and thereby reduce 79,000 cases of foodborne illness per year. It includes the following: (1) assure biosecurity, (2) reduce pests such as rodents and flies, (3) chicks must be SE free, (4) test the environment of 14- to 16-week-old pullets for SE, and (5) if not free of SE, clean and disinfect facilities thoroughly and test eggs.

The details of the Egg Rule are summarized in Figure 14.3. First, test the bird's environment for SE, particularly the freshest manure and by swabbing the manure belt. If the environment of a facility is positive for SE, eggs must be tested for SE. One thousand eggs from a single day's production are subject to testing. The FDA considers that eggs that are positive for SE are adulterated; if representative eggs are positive, all eggs are to be withdrawn from marketing as shell eggs for the life of the flock. They can be broken and pasteurized to kill SE and other microbial contaminants. The FDA requires that there must be four negative tests before eggs can be sold as shell eggs.

Other important approaches include (1) vaccination against SE; (2) treatment of feed (e.g., by heating

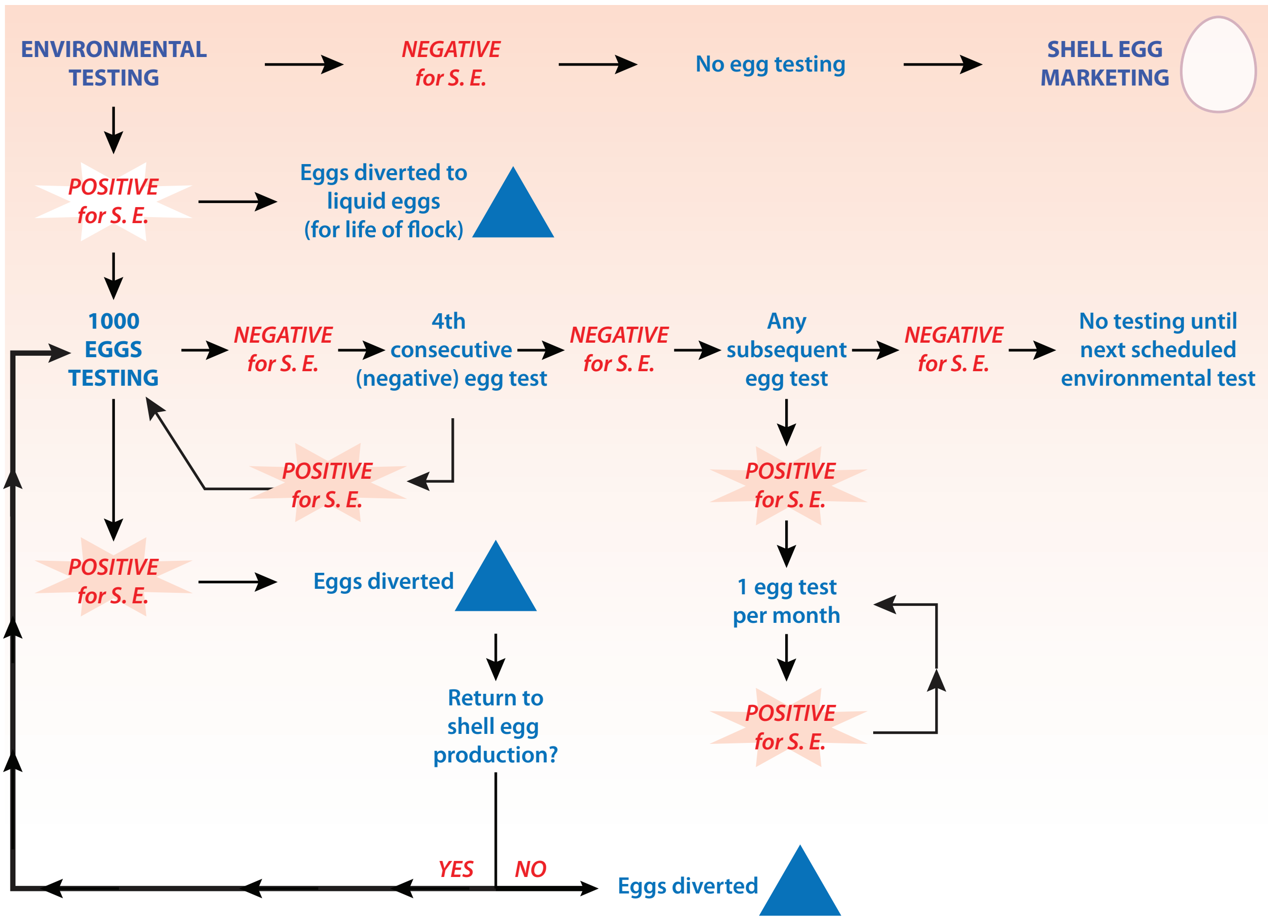

Figure 14.3 The decision tree for the FDA's Egg Rule.

or treatment with heat and pressure) to destroy SE; (3) removal of manure from cages; (4) effective biosecurity, including limiting visitors, the prevention of cross contamination between houses by either equipment or personnel, the prevention of wild or feral animals or birds entering layer facilities (e.g., having an effective rodent control program), employees prohibited from owning birds (exotic or poultry) at home, and sanitation; and (5) holding eggs at 45°F (7.2°C) within 36 hours of lay.

14.6 Food Safety Aspects of Poultry Meat

Introduction

Contamination with *Salmonella* and other bacteria can occur both on the outside surface and in the eviscerated body cavity of chickens, turkeys, and other poultry. This is the result of spilling gut contents, particularly from the colon and ceca (equivalent of the large intestine and rectum in mammals) and the regurgitation of the contents of the crop. The numbers of *Salmonella* in the crop contents increase when feed is not present in the crop. Paradoxically, feed is withheld for a period before slaughter in an attempt to reduce release of feces. According to the FDA, contamination of poultry with pathogens has decreased (see Table 14.2).

To be sold in the US, meat must be inspected by the USDA. Inspections are conducted by the FSIS. The method of on-line inspection is a visual (organoleptic) method with examination of both viscera and carcass. Carcasses failing inspection are considered condemned or as condemnations and are removed from the line.

Table 14.2 Recent changes in the contamination of poultry meat with *Salmonella*.

Contamination	Year 1	Year 2
Salmonella	**2008**	**2014**
Ground turkey	19%	6%
Chicken	15%	9%
***Salmonella* resistant to ceftriaxone**	**2009–2011**	**2015**
Ground turkey	22%	4%
Chicken	38%	5%

Data from the FDA.

HACCP-Based Inspection

The Pathogen Reduction and Hazard Analysis and Critical Control Point (HACCP) System was adopted as the new system for meat and poultry inspection in the United States in the late 1990s. This science-based system replaced traditional meat inspection. The system includes the establishment of standards for food safety and nonfood safety defects with the goal of reducing foodborne pathogens, ongoing verification of implementation, and educational/training programs for HACCP teams. The system identifies what it calls Critical Control Points (CCPs) and uses various system approaches to reduce hazards. Examples of CCPs include (1) scalding freshly killed chickens in a common bath to loosen feathers, (2) defeathering many birds with the same rubber fingers, (3) eviscerating birds with a properly adjusted machine, and (4) cooling defeathered chickens in a common chill bath.

These CCPs markedly reduce microbial contamination of the carcass. Prior to removal from poultry houses for transportation and slaughter, all feed is withdrawn. This is to assure that the gastrointestinal tract is empty. Thus, during processing, the potential for contaminating the carcass with either feces or other gut contents is greatly reduced.

Role of the Pre-Scalder Brushes to Reduce Pathogens

The pre-scalder brushes remove 90% of the feces contaminating the carcass. The scalders decrease the numbers of microbes, including pathogens, on the skin of the carcasses. To further reduce pathogens on the carcasses, poultry carcasses are cooled to less than 39.2°F (4°C) in the chiller within four hours of slaughter. The chiller contains antimicrobial chemicals such as the following:

- Chlorine at a pH below 6.0. When chlorine is dissolved in water, hypochlorous acid (HClO) is formed.
- Peroxyacetic acid (organic peroxide O-OH) (up to 220 ppm). This chemical is used when the poultry are to be exported to countries where chlorine is banned.
- Other antimicrobials include bromine, organic acids, acidified sodium chlorite, and chlorine dioxide.

TEXTBOX 14D

Processing and Pathogens

Scalding has been demonstrated to be effective in causing at least 3-log reductions in the numbers of *Salmonella typhimurium* and *Campylobacter jejuni* on the skin of chicken carcasses (Yang et al., 2001). Chillers are effective in reducing bacteria and specific pathogens (see Textbox 14D Table 1). It is noted that contaminated chillers can increase both *Campylobacter* and *Salmonella* numbers on the carcasses (Smith et al., 2005).

Textbox 14D Table 1 Effect of the chiller on microbial and pathogen contamination on chicken carcasses.*

Contamination	Carcass (cfu $\log_{10}$ per Carcass)—Pre-Chiller	Carcass (cfu $\log_{10}$ per Carcass)—Post-Chiller (Low Volume)	Decrease Post-Chiller—$\log_{10}$ (Absolute)
Total	8.5 ± 1.1	6.0 ± 0.3**	2.5 (300 fold)
E. Coli	6.8 ± 0.6	4.8 ± 0.2**	2.0 (100 fold)
Enterobacteriaceae	6.1 ± 0.8	4.8 ± 0.1**	1.3 (20 fold)
Campylobacter	7.1 ± 1.1	4.4 ± 0.2**	2.7

*Data is mean ± standard error of the mean; cfu = colony forming units.
**Different from pre-chiller $p < 0.01$.

Data from Northcutt et al., 2006.

14.7 Food Safety in Food Manufacturing, Retailers, and Restaurants

Food manufacturers, retailers, and restaurants need to follow good practices to assure that poultry and eggs are handled correctly to reduce or eliminate contamination with pathogens. FDA Food Code 2009 provides definitive guidance on food safety measures in retail operations such as grocery stores and restaurants. Problems arise from mishandling poultry meat and eggs.

The FDA requires that the retailer refrigerate shell eggs promptly when they are received and by storing the eggs at 45°F (7.2°C) or cooler. Similarly, meat should be stored frozen and thawed at 40°F (4.4°C) or cooler. According to the FSIS, temperatures between 40°F (4.4°C) and 140°F (60°C) are unsafe, with pathogens multiplying with increasing rates of replication at higher temperatures. Pathogens in poultry meat and eggs are killed with adequate cooking (to over 160°F or 71°C). The numbers of pathogens are critically important as people have to consume the infective dose.

Cross-contamination (e.g., contamination of foods by "drippings" from uncooked poultry) can occur in stores or restaurants (see Textbox 14E). It is particularly hazardous when poultry drippings contaminate ready-to-eat items. Also, only pasteurized liquid eggs should be used in such uncooked food items as in house-made salad dressings (e.g., Caesar salad, mayonnaise) and eggnog. There is a significant hazard when unpasteurized shelled eggs are used in the preparation of raw food items.

Example of Retailer Improving Food Safety

In the US, Walmart implemented further food safety measures that included (1) the reduction of transmission of *Salmonella* from primary breeders, (2) biocontrol and disease prevention "best practices," (3) whole chicken processing to achieve 4-log reduction of *Salmonella*, and (4) interventions with parts to achieve a 1-log reduction of *Salmonella*. These measures were successful, with the incidence of the contamination of chicken meat with *Salmonella* decreasing from 17% in 2014 to 2% in 2016.

14.8 Food Safety and the Consumer

While food manufacturers and grocery stores should produce and sell safe products, the consumer has a role in food safety as well. Eggs and poultry meat may harbor pathogens that can give rise to foodborne diseases in the human population. Pathogens in poultry meat and eggs are killed with adequate cooking (over 160°F/71°C for eggs and egg dishes or 165°F/74°C for poultry meat; see Figure 14.4). Pasteurized

TEXTBOX 14E

A Deeper Dive: Restaurants Following the FDA Code

Eating at restaurants is convenient and even fun but can also be risky. For instance, Kimura and colleagues (2004) concluded that "eating chicken outside of the home" was the risk factor for illness from SE in a study of outbreaks in the USA. Similarly, undercooked liver used to prepare liver pâté was the source of an outbreak of *Campylobacter* infection in Scotland (O'Leary et al., 2009). Among the requirements of the FDA Food Code 2017 is that managers of restaurants should be knowledgeable about food safety and should ensure that restaurants they manage have clear food safety policies that are being adhered to. From a survey of over 300 restaurants, it is clear that this is not the case in many restaurants (Green Brown et al., 2013) (see Textbox 14E Table 1).

Textbox 14E Table 1 Do restaurants follow the Food Code on issues relevant to poultry?

Items in FDA's Food Code Relevant to Poultry	Percent of Restaurants Surveyed that Followed Code
Cleaning policy in place.	91
Wash, rinse, and sanitize surfaces that come in contact with poultry.	83
Minimal handling of raw poultry meats without wearing single-use disposable gloves.	72
Raw chicken always rinsed or washed before use.	42
Designated separate boards for cutting up raw poultry and other meat.	60
Final cooked temperatures measured by thermometer.	46
Thermometer calibrated daily.	28
Managers that knew what temperature raw chicken needed to be cooked for it to be safe to eat (165°F, 74°C).	43

Green Brown et al., 2013.

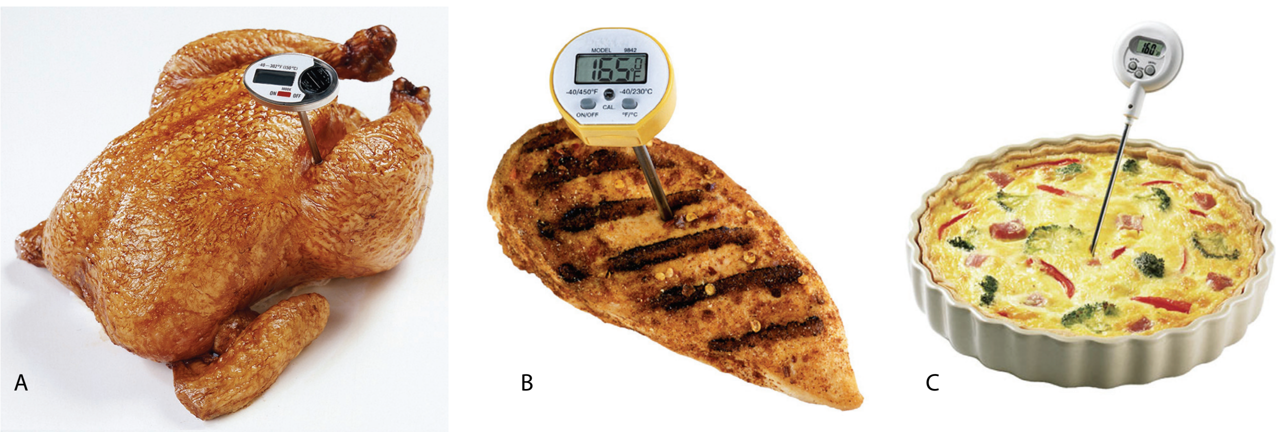

Figure 14.4 Use a food thermometer to ensure that the center of poultry meat has reached the critical temperature where pathogens are killed. (A) Whole chicken; (B) Chicken breast; (C) Egg dish.

liquid eggs can be consumed raw, such as in eggnog, however table eggs should not be used to prepare raw food items. Moreover, uncooked cookie dough, cake mixes, or pastries containing raw eggs should unfortunately not be eaten. Again, according to the FSIS, it is not a good idea to purchase cracked eggs.

There have been numerous food safety educational programs with very similar content (instructions) to ensure food safety. An example is the Food Safe Families campaign sponsored by the CDC, FDA, and USDA. The campaign has four steps:

- **Clean.** This includes washing your hands before handling food and after handling raw meats, washing any surfaces used for preparing food before and after use, and washing fruits, salad items, and vegetables.
- **Separate.** It is critically important not to cross-contaminate raw poultry, meat, or eggs with ready-to-eat foods, such as salads and deli meats.
- **Cook.** Poultry meat and eggs should be cooked to temperatures shown to kill pathogens; 165°F (74°C) for the center of poultry meat (see Figure 14.2) and 160°F (71°C) for eggs and egg dishes. Fried and other eggs should be cooked until both white and yolk are firm.
- **Chill.** Fresh foods, including eggs and poultry, should be refrigerated as soon as possible.

14.9 Allergens and Food

Food allergies are relatively common in both children and adults. People can be allergic to eggs or poultry meat (chicken, turkey, ducks, and other poultry species). According to the CDC, 4–6% of children and 3% of adults have at least one food allergy in the US. Some children grow out of their allergies.

Food allergies are commonly against the components of foods. Almost all (~90%) food allergies are against components of peanuts, tree nuts, soy, wheat, milk, shellfish, fish (finfish), and eggs. About 2% of food allergies are due to eggs. Symptoms of an allergy range from the mild (e.g., runny nose, tingling fingers and/or lips, and hives) to anaphylaxis to death. Obviously, if someone is allergic to a specific food, they should avoid the food. However, the mislabeling of foods can occur and not only can lead to significant risks to people with allergies but also financial problems to the manufacturer due to recalls and loss of reputation.

Anaphylaxis is a severe allergic reaction that appears to be increasing particularly in children. Anaphylaxis can be fatal. Symptoms of an anaphylactic reaction include hives, flushed skin, nausea and/or diarrhea, abdominal pain, edema, swollen tongue and lips (see Figure 14.5), swelling around the eyes, wheezing, tingling fingers, and a sense of doom. This is life-threatening and requires immediate hospitalization. Epinephrine should be given immediately via an Epi-Pen® (Figure 14.6).

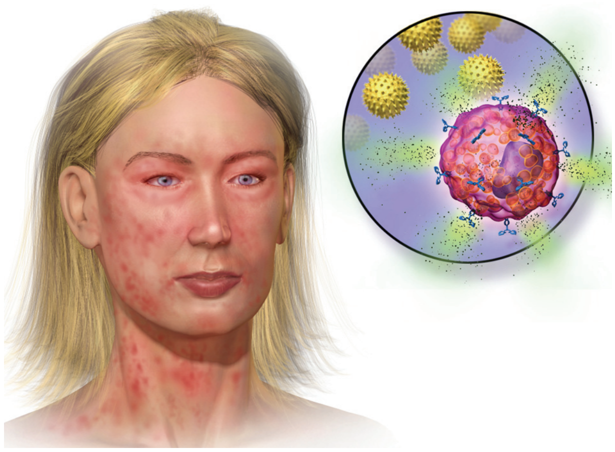

Figure 14.5 People with anaphylaxis can develop swollen lips, eyes, and other areas on the face; hives on the skin; and respiratory distress, among other symptoms, due to the release of histamine and other inflammatory compounds from mast cells (see inset).

Figure 14.6 In the event of an anaphylactic reaction, the individual or someone close should use an Epi-Pen® (an auto-injector) to inject epinephrine (adrenaline) into the thigh muscle. (Source: David Smart/Shutterstock)

Anaphylactic shock occurs when blood pressure falls to very low levels and the airway is completely or almost completely occluded. The person will struggle to breath, be dizzy or confused, and may lose consciousness. Immediate hospitalization and treatment is required, including provision of oxygen, and, if the airway is compromised, intubation with an endotracheal tube.

TEXTBOX 14F

Anaphylaxis

It is estimated that anaphylaxis affects 1.6% to 5% of the population in their lifetimes and appears to be increasing, particularly in children. The yearly rate of anaphylaxis hospitalizations is about 2 out of every 100,000 people, with the mortality rate of about 3–5 deaths per 10 million people each year (Mulla et al., 2011; Vetander et al., 2012).

14.10 Chemicals and Pesticides in Poultry and Eggs

Consumers have concerns about pesticides. Consumption of organic food is increasing as consumers look for pesticide-free foods. There are extremely low levels of pesticides and other toxic chemicals in poultry meat or eggs, reflecting the high quality standards in poultry feed production. However, free-range poultry can take in pesticides and other toxic chemicals from the soil if it is present. There is evidence of incorporation of fat-soluble toxins such as dioxin, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls (PCBs) into the yolks and fatty tissue of free-range poultry.

14.11 Antibiotics in Poultry and Eggs

Antibiotics are used therapeutically to fight bacterial diseases in poultry, livestock, and people. Strict regulations govern withdrawal times before products can be marketed. Antibiotics have been used as growth promotants in poultry and pigs since the 1950s. Due to the concern that this nontherapeutic use of antibiotics is leading to antibiotic-resistant bacteria, the use of antibiotics as growth promotants is decreasing.

14.12 Irradiation of Poultry

Irradiation of foods greatly reduces the contamination in microorganisms that are either pathogens (cause disease) or food spoilage organisms. The ionizing radiation is generated from a radioactive source (e.g., cobalt 60 or cesium 137) or a linear accelerator. There is abundant evidence that both processes are safe with no contamination of the food. Radiation pasteurization of meat extends the shelf life and represents a major step to reducing foodborne disease.

For over 30 years, food for astronauts and some spices have been irradiated. The United States approved irradiation of poultry in 1990 as well as beef and pork in 1999; however, consumer concerns have led to a failure to use this technology. The term "radiation" can conjure up visions of nuclear weapons and power stations, and some have pushed for use of the names "cold pasteurization" or "cold sterilization" instead.

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15

Incubation

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Know the history of artificial incubation.
2. Know the differences between a chicken embryo and a mammalian embryo.
3. Understand the major factors influencing embryonic development.
4. Understand processes in embryonic development such as gastrulation, neurulation, and cell migration.
5. Know the germ layers in an early embryo.
6. Know what tissues come from each germ layer.
7. Know what tissues come from each somites.
8. Know what the embryonic membranes are and what they do.
9. Define hatchability.
10. Know how are eggs stored and how long they can be stored.
11. Explain how hatchability of stored eggs can be improved.
12. List the roles of a hatchery.
13. Explain what a setter and hatcher are and know when and why eggs are transferred between the two.
14. Know what a "rot" and an "exploder" are.
15. List the major factors for successful egg incubation.
16. Explain what pulling is.
17. Know how chicks are sexed and transported.
18. Know how chick quality is assessed.
19. Know how hatchery waste is disposed of.

15.1 Introduction

The time required for incubation varies for different species of birds. The normal incubation periods for domesticated and captive species of birds is shown in Table 15.1. Why is the development of poultry embryos important? This is the basis of poultry production. Small changes in hatchability and chick quality markedly influence production of chicks and poults. The major factors influencing successful poultry production are genetics and nutrition. We can add to the list "incubation and chick quality."

Factors controlling embryonic development, assuming fertility, include (1) the incubation environment, which is human-controlled; (2) genetics, which are strongly influenced by humans—including genes controlling embryonic development, metabolism, and growth, along with the avoidance of lethal or sublethal genes; (3) the size and condition of eggs, which are influenced by the hen and humans (during grading); and (4) bacterial invasion (and diseases), which are strongly influenced by humans. This can be analo-

Table 15.1 Length of incubation for poultry and other domestic bird species.

Species	Duration of Incubation (Days)
Galliform poultry	
Chicken (broiler or layer)	21
Turkey	28
Water fowl	
Domestic duck	28
Muscovy duck	33–35
Domestic goose	28–35
Ratites	
Emu	49–55
Ostrich	42
Game birds	
Bobwhite quail	23–24
Guinea fowl	27
Japanese quail	17
Peafowl	28
Pheasant	24
Other	
Canary	13
Parakeet	19
Pigeon	18

gized to the nature versus nurture debate for people; nature being assumed to be genetics and nurture being rearing. However, developing embryos depend on the composition of the eggs (supplying nutrients), which is markedly influenced by the nutrition of the hen.

Incubation is the development of the embryo in the fertile egg before hatching. Incubation is either **natural incubation**, with a setting hen hovering over eggs, or **artificial incubation** (or **incubation**), where incubation is independent of the hen. Eggs have been incubated artificially for over two thousand years. Aristotle (384–322 BC) wrote about Egyptians incubating eggs in decomposing manure to furnish heat or with brick incubators heated with fires. At about the same time, artificial incubation was developed in China in about 246 BC.

For many years, the various techniques of artificial incubation were closely guarded and only passed from one generation to the next, often in a family. The hatchery operator determined the proper temperature by placing an incubating egg in the socket of his or her eye! Temperatures in the incubator were changed by the following: The temperature within the incubator was altered by moving the eggs, adding more eggs to use the heat created by embryological development, and controlling the air flow. Humidity was not a problem, for these primitive incubators were located in highly humid areas or in decomposing manure. Turning was done up to five times daily, after the fourth day of incubation. The Smith incubator (patented in 1918) was the forerunner of today's incubators. Today's incubators have capacities of more than 500,000 eggs and are equipped with sophisticated controls to maintain optimum conditions for hatchability.

15.2 Poultry Reproduction

Poultry reproduction is markedly different from the reproduction of mammals, beginning with the large yolky egg. During the development of the yolky ovum, yolk is incorporated and the **germinal disc** develops, which can be seen as a small white plaque on the surface. The germinal disc sequesters and when complete contains 99% of the oocyte organelles. This region also concentrates proteins and messenger (m) RNA that are required for fertilization and directs early embryonic divisions prior to activation of the embryonic genome.

Other obvious differences are that the egg is fertilized in the infundibulum, surrounded by egg white proteins, water, and a shell, before being expelled from the body. In contrast, the fertilized egg (conceptus) in mammals remains in utero until birth. Also, in higher animals, reproduction is possible only after the ovum (female gamete) is fertilized or united with the spermatozoon (male gamete). In chickens, while fertilization is a requisite for reproduction, it is not a necessary preliminary to egg-laying; a hen can lay continuously without the male. Table 15.2 summarizes information relative to the reproduction of poultry. Once the egg is laid, bacteria can adhere to the egg. It takes about 3 minutes for the cuticle to dry after the egg is laid. The shell is permeable, being porous to water, oxygen, and carbon dioxide.

The Importance of Yolk

The yolk is used by the embryo towards the end of incubation and following hatching. Yolk provides proteins, fats, vitamins, minerals, and water. It is drawn into the body of the chick embryo beginning about day 19.

Table 15.2 Comparison of reproduction in chickens and mammals.

Parameter	Chicken	Mammal
Ovary	1	2
Female ducts	1 "oviduct" comprised of infundibulum, isthmus, magnum, uterus, and vagina.	2, comprised of oviduct, uterus, cervix, and vagina.
Size of egg	2.5 cm	0.1 mm
Duration in female tract	23–25 hours	Pregnancy length from ~2 weeks to over a year.
Number of cells when laid/born	10^5	10^{12}
Duration of incubation	21 days	N/A
Potential offspring per year	~250	1 (cattle/sheep); 15 (pigs)

Definitions

Embryo: In poultry and other birds, the word embryo covers all development of the chick from fertilization to hatching.

Mammals: In mammals, the term embryo covers the period of time from implantation to the time when all the major organs are formed and true bone (with calcification) begins. In mammals, the conceptus is called the fetus after the embryonic stage.

Fertile eggs: The number/percentage of fertile eggs is determined by candling eggs to establish whether embryonic development has begun (see Section 15.7). The term "fertile egg" is widely used, however it is a misnomer. It really is the following: an egg that has been fertilized and embryonic development has begun.

$$\text{Fertile eggs (\%)} = \frac{\text{Chicks fertile}}{\text{Total eggs}} \times 100$$

Hatching: The process by which the embryo escapes/leaves the confines of the egg. This is analogous to the process of parturition (birth) in mammals. Newly hatched chicks (called baby chicks) are sometimes called neonatal. Being pedantic, this is not correct as natal means born.

Hatchability: This is the number of eggs hatched divided by the number of eggs set. The USDA defines it Hatchability (%) = chicks hatched × 100 ÷ eggs set. For example, 85 hatched chicks × 100 ÷ 100 eggs set = 85% hatchability.

Percentage hatch of fertile eggs:

$$\text{Hatch of fertile eggs (\%)} = \frac{\text{Chicks hatched}}{\text{Fertile eggs}} \times 100$$

For example, if the hatchability is 85% and fertility is 95%, then the hatchability of fertile eggs is 89.5%. The advantage of calculating the percentage of fertile eggs is it facilitates management to differentiate between fertility problems and hatchery problems. The goals at peak production for broiler breeders is 96.7% fertile with 93.5% hatch of fertile. Hatchability is improved by best practices in egg collection, grading, and storage together, of course, with incubation.

Parthenogenesis: The development of unfertilized eggs. It can occur in chickens and turkeys. Most parthenogenetic embryos die but about 1% complete development and hatch.

TEXTBOX 15A

A Deeper Dive: Maternal (Nongenetic) Influences on Embryonic Development

There is a large effect of maternal age (stage of egg production) on egg size. In turn with the greater egg size, there is a concomitant increase in embryo weight at day 21. Moreover, the yolk sac is much larger at day 21 and contains more fat (see Textbox 15A Table 1) (Yadgary et al., 2010).

Textbox 15A Table 1 Effect of maternal age (stage of lay) of broiler breeder hens on embryonic development.

Parameter	30 week	50 week
Egg weight (g)	59.0^a	71.3^b
Embryo at d 21 (g)	36.4^a	43.0^b
Yolk sac at d 21 (g)	6.1^a	9.0^b
Protein (mg/g)#		
d 0 (egg not incubated)	179^b	156^a
Embryo d 15	211	212
Embryo d 21	294	293
Fat (mg/g)#		
d 0 (egg not incubated)	55.2^b	53.0^a
Embryo d 15	298	303
Embryo d 21	196^a	294^b

[a, b] Different superscript letters indicate difference.

[#] Protein and fat in yolk/yolk sac. Egg shell temperature is used as a surrogate measure for embryo temperature.

Data from Yadgary et al., 2010.

15.3 Development of the Chick Embryo

The chick embryo (Figure 15.1) has been a model for the study of the processes of development for over 2000 years. An example of this was in Classical Greece and includes the work of Aristotle (384–322 BC). The Hamilton–Hamburger stages of embryonic development are shown in Appendix III Table 1.

Earliest Development

The egg is fertilized within about one hour of ovulation. After the fusion of the haploid gametes, there is the first cell division and **meroblastic** cleavage (surface cleavage) across the surface of the entire **area pellucida** in the **animal pole** of the egg (future dorsal side). The word pellucid means transparent. The circular area pellucida is surrounded by the **area opaca** with a **marginal zone** between them. There are then multiple mitosis (cell divisions). Initially cleavage is meroblastic but quickly shifts to provision of cells and ultimately to about 100,000 cells when eggs are laid. By this time, at oviposition (when the egg is laid), there is a layer of cells a **blastoderm** resting above the yolk with a **subgerminal space** between the two. The blastoderm cells will go on to form the chick and the membranes around it (see Figure 15.1).

The Role of the Hen in the Development of the Embryo

We think of the development of the embryo with it sitting in an incubator, however for the first day of development it is in the oviduct. The hen provides heat and the developing egg is rotated at an amazing rate of 10–12 times per hour. There is separation within the yolk with the light components at the top. It is on these components that the early development of the embryo occurs.

Formation of the Two Cell Layers of the Blastoderm

Hypoblast cells cease to be part of the blastoderm, forming islands of cells beneath what is becoming the epiblast. Secondary hypoblast cells migrate towards the anterior from the posterior margin and join with the clusters or islands of hypoblast cells to form a layer (by 16 hours of incubation see Figure 15.1). **Epiblast cells** become the embryo proper and the vast majority of the embryonic membranes. **Hypoblast cells** become parts of the yolk sac and the yolk sac stalk connecting the sac to the endodermal intestine. The **blastocoel** is the cavity between the epiblast and the hypoblast layer.

Gastrulation

Gastrulation is the formation of a three-layered conceptus creating a mesoderm layer between the ectoderm and endoderm. The three layers are the germ layers.

The mechanism to achieve this gastrulation is understood. A thickening of the epiblast in the posterior blastoderm can be seen (at ~21 hours of incubation). This is due to cells migrating and then accumulating at the **primitive streak** (see Figures 15.1 and 15.2). The migrating cells pass into the blastocoel through the **primitive streak**. A depression forms in the primitive streak which is called the **primitive groove**. The first cells that pass into the blastocoel are the endoderm progenitor cells including some from the lateral blastoderm. This process moves from posterior to anterior forming the endoderm. The mesoderm progenitor cells then migrate through the same process, becoming the third cell layer. The ectoderm progenitor cells remaining in the epiblast proliferate and completely surround the yolk.

When the primitive streak reaches its anterior limit, there is a swelling called the **primitive knot** or **Hensen's node** (see Figure 15.1). The head will form anterior to Hensen's node. Some of the cells that migrate through Hensen's node go on to form the **notochord** (see Figure 15.1); this being an embryonic structure of all chordates running from the anterior to posterior. Later development also progresses predominantly from anterior to posterior.

Germ Layers

Ectoderm develops into the epidermis, feathers, lens, cornea, and olfactory and mouth epithelium. The **neural crest** forms the peripheral nerves (sympathetic and parasympathetic), adrenal chromatin cells, and melanocytes. The **neural tube** forms the brain, spinal cord, motor neurons, and retina.

Endoderm develops into the intestines, lungs, pancreas, and liver.

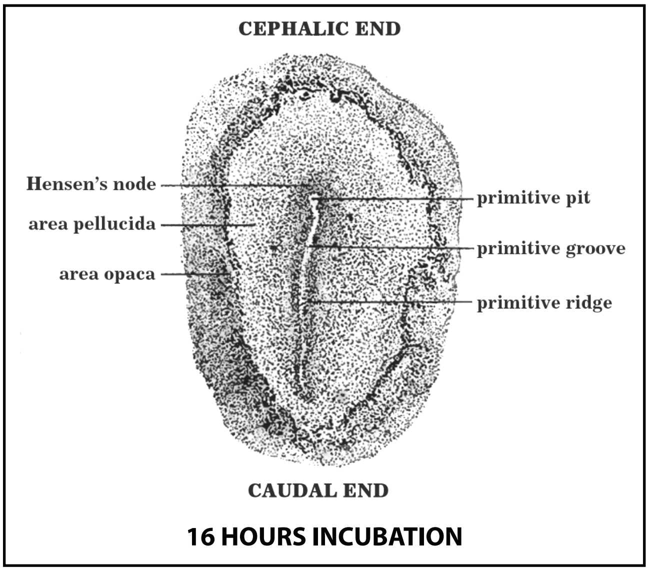
Mesoderm develops into somites (somatic mesoderm) and splanchnic mesoderm.

Later Development

Somites are bilateral with a pair on each side. These are segmental. This segmentation is formed sequentially from the head to the tail on either side of the neural folds (see Figures 15.1 and 15.3, and Appendix

Prior to egg laying, there is fertilization followed by multiple mitotic divisions with initially cleavages and then cell divisions with there being 20,000 cells in the fertilized egg when laid. The cells form the blastodisc. This has a one cell thick clear area, the area pellucida. This has an underlying fluid filled subgerminal cavity and the cells of this area will form the embryo. Around the area pellucida is the area opaca with deep cells.

A. By 16 hours of incubation, the beginnings of differentiation are clearly seen with primitive groove with on its sides, the primitive ridge. There is directionality with Hensen's node at the end that will become the head (cephalic end) and other end being the caudal end or tail end. The primitive groove is essential to formation of the germ layers; first the endoderm and then the mesoderm.



B. By 18 hours of incubation, there are new structures: the notochord (the spinal column builds on this later) and the neural plate (this will form the brain and other nervous tissues). Moreover, Hensen's node is moving towards the cephalic end.

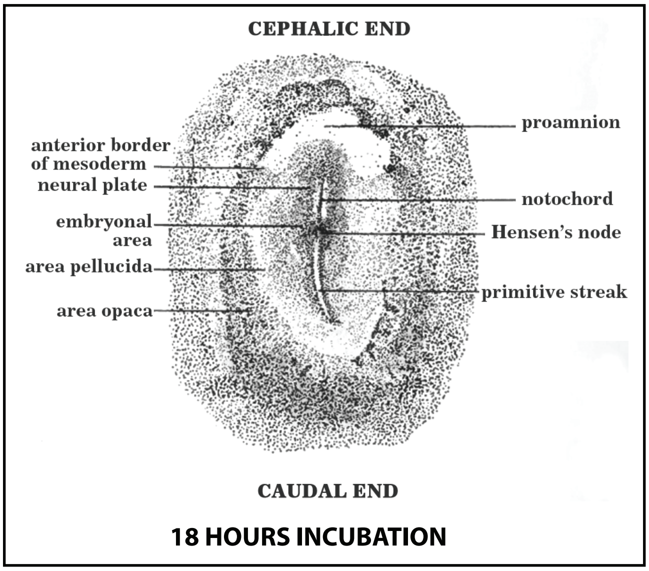
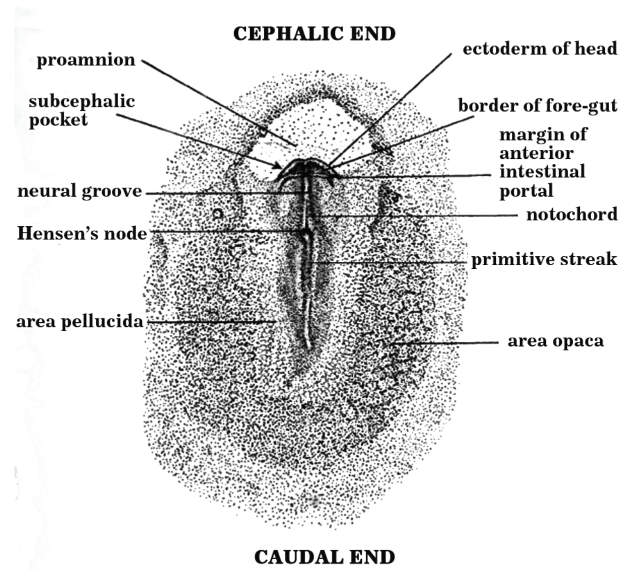
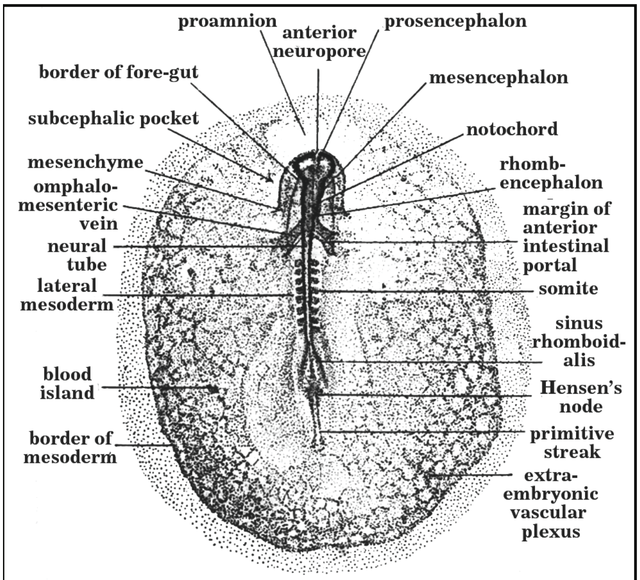


Figure 15.1 Early development of an embryonic chick. (Modified from B. M. Patten. 1920. *The Early Embryology of the Chick.*) *(continued)*

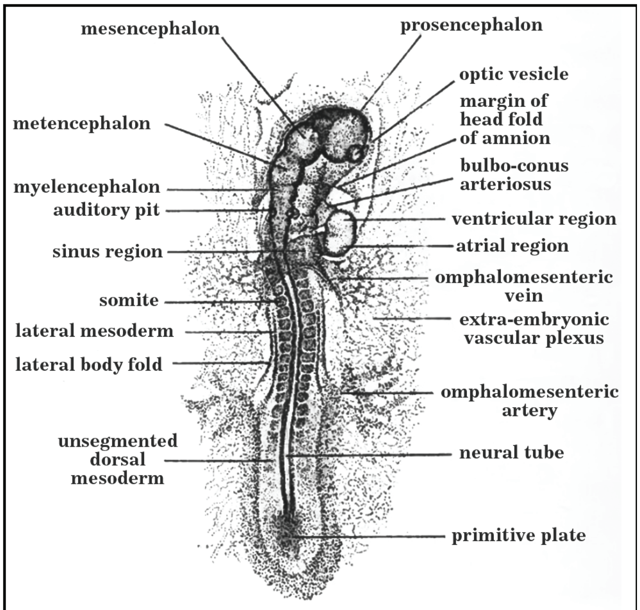
C. By 21 hours of incubation, the notochord is growing. The neural tube is forming (eventually forming the brain and spinal cord). The formation of the gut is beginning. Hensen's node has moved towards the cephalic end.



21 HOURS INCUBATION



27 HOURS INCUBATION



43 HOURS INCUBATION

D. By 27 hours of incubation, the cardiovascular system is beginning with blood formed. The neural tube has differentiated with three brain regions seen—the prosencephalon (forebrain developing into cerebrum, thalamus and hypothalamus), the mesencephalon (the mid-brain) and the rhombencephalon (the hindbrain developing into the medulla, pons, and cerebellum). There is clear segmentation with the development of somites. Hensen's node has moved close to the cephalic end.

E. By 43 hours of incubation, the cardiovascular system is developing with a functioning heart. The development of the eyes and ears have begun. Somite development has continued to the cephalic end. rhombencephalon has differentiated into the metencephalon (developing into the pons and cerebellum) and myelencephalon (developing to the medulla oblongata). There is a beginning of flexure with the embryo curved.

Figure 15.1 *(continued)*

A.–B. Migration of differentiated cells through the primitive streak forming the basic germ layers. (Modified from B.M. Patten.1920. *The Early Embryology of the Chick*).

C. Migration of cells forming the mesoderm (and ultimately the tissues derived from it—namely the skeleton, muscles, cardiovascular system etc.).

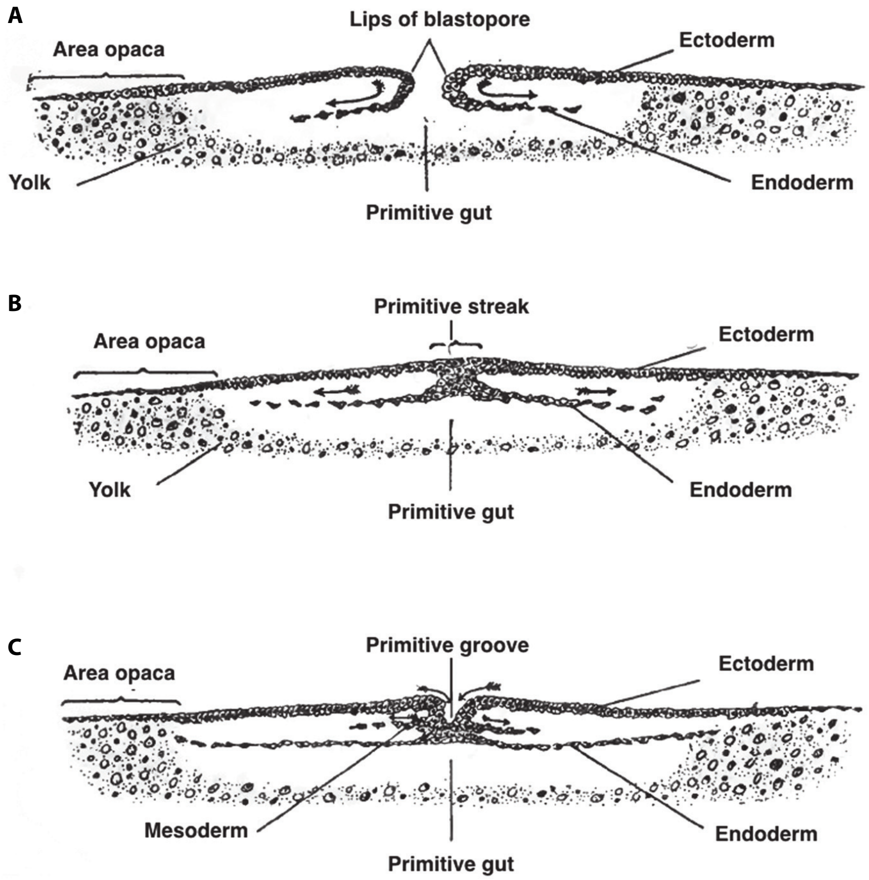


Figure 15.2 Migration of differentiated cells through the primitive streak forming the basic germ layers. (Modified from B. M. Patten. 1920. *The Early Embryology of the Chick*.)

III Figures 1–5). It takes about 90 minutes for the formation of each somite from the unsegmented paraxial mesoderm with there being cyclic expression of a transcription factor from the *c-hairy1* gene in the pre-somite mesoderm. This gene is the avian homologue (equivalent) of *hairy*, the segmentation gene in insects and, specifically, the model species *Drosophila melanogaster*.

The somites develop into the following: dermatome into dermis of skin, myotome into skeletal muscle, sclerotome into skeleton, and syndotome into tendons.

Embryonic Membranes

The extraembryonic membranes are illustrated in Figure 15.4. There are 4 membranes:

1. **Yolk sac**: Composed of splanchnic mesoderm and endoderm. It contains blood vessels, grows and will surround the yolk, and mobilizes nutrients in the yolk.
2. **Amnion**: Composed of somatic mesoderm and ectoderm. This provides a liquid environment for developing embryo to set on.
3. **Chorion**: Composed of somatic mesoderm and ectoderm. The chorion fuses the inner shell membrane to the allantois and helps that membrane carry out its functions.
4. **Allantois**: Composed of splanchnic mesoderm and endoderm. It surrounds and protects the embryo, stores excretory products (allantoic sac), and the blood vessels pass through it. It also combines with chorion, producing the chorioallantoic membrane (CAM). This in turn allows respiration through a gaseous exchange (oxygen in, carbon dioxide out) at the air sac, and digestion of albumen to yield amino acids and the breakdown of the shell to release calcium.

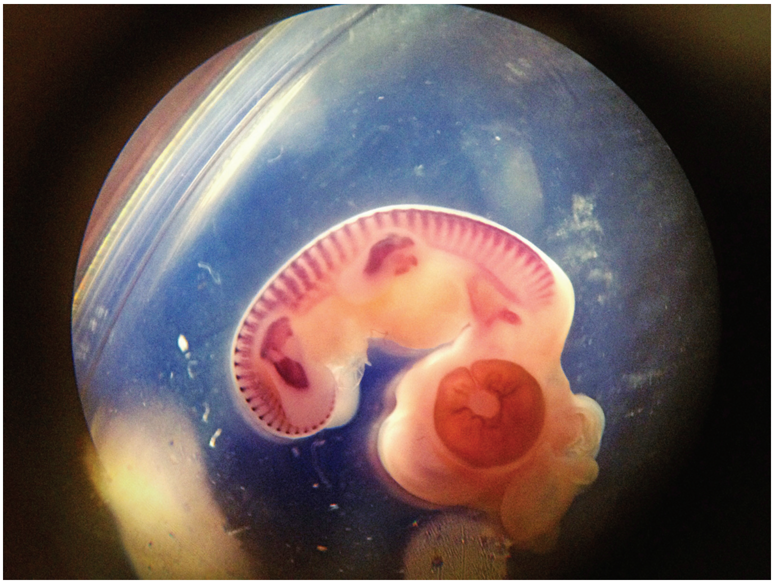


Figure 15.3 Chicken embryo at Hamilton-Hamburger stage 21 (3.5 days of incubation). The somites (~44) run from the head to the tail. The somites are much more clearly seen by a marker, namely MyoD. Also note that the large eyes are pigmented. The MyoD is visualized following in situ hybridization allowing visualization of expression of a protein regulating muscle differentiation, namely MyoD. (Source: Simone Castellana/Wikimedia Commons)

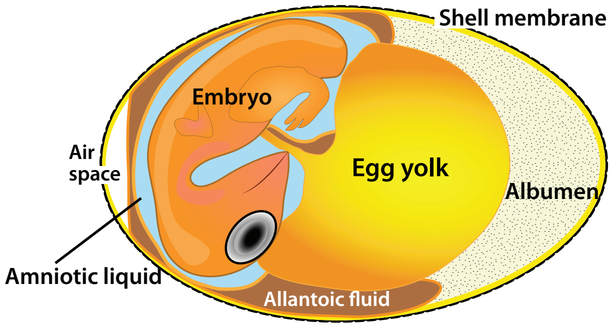


Figure 15.4 A developing chicken embryo shown with amnion containing amniotic fluid, the allantois containing allantoic liquid (fluid) and the yolk sac containing yolk. (Source: Designua/Shutterstock)

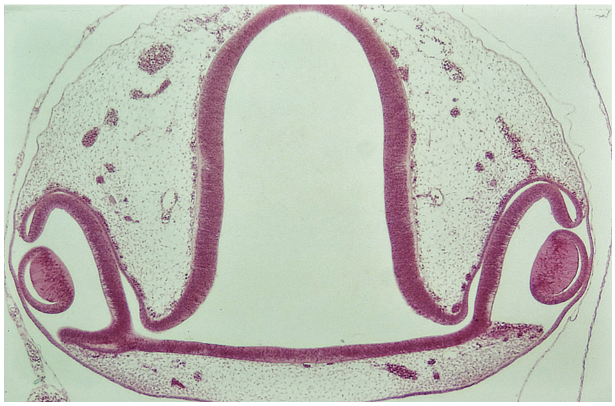


Figure 15.5 A developing brain (as a vesicle) and eye with lens shown in histological section. (Source: Rollroboter/Wikimedia Commons)

Formation of the Neural Tube

There are neural progenitor cells in the ectoderm. These are called the **neural plate**. In the process of **neurulation**, the **neural tube** is formed in the midline of the neural plate starting from the head (or **cephalic** region) and progressing towards the tail (or **caudal** region). This **neural groove** lies over the **notochord** with the notochord playing a critical role in inducing changes in the neural groove cells (beginning about 21 hours of incubation; see Figure 15.1). The formation of the neural tube is completed when neural folds meet and fuse. The process starts at about 24 hours of incubation. The anterior neural tube goes on to form the brain (see Figure 15.5).

Formation of the Limbs

The first signs of the developing limbs are the limb buds; these being circular bulges that can be readily seen. Mesoderm cells, such as myotome and sclerotome cells, migrate from the somites (somite 21 for wings) to the limb bud areas. These cells release growth factors, probably fibroblast growth factor 10, to induce the overlying ectodermal cells to form the apical ectodermal ridge, and this in turn plays a critical role in the development of the wings and legs.

Embryonic Metabolism

There is a marked shift in metabolism between embryonic and post-hatching life.

Gluconeogenesis + Glycogen Synthesis/Breakdown

Proteins Albumen/Yolk → Glucogenic amino acids in blood → Glucose Liver ↔ Glycogen Liver

Glucose Liver ↙ Glucose in blood ↓ Muscles → ATP

Glucose Liver ↘ ATP

and/or

Fatty Acid β Oxidation

Fatty acids → CO_2 + ATP

Post-Hatch Metabolism

Starch (Intestine) → Glucose (All tissues) → CO_2 + ATP

Incubation Environment and Embryonic Development

The environment within the incubator influences embryonic development. Factors include temperature, carbon dioxide, and oxygen. The extraembryonic blood vessels are critical to gaseous exchange and the nutrition of the developing embryo (see Figure 15.6).

During incubation, higher temperatures speed up embryonic development while lower temperatures slow embryonic development down. Incubation temperature and other environmental conditions (e.g., carbon dioxide) in the incubator have different effects on different organs. In addition, embryonic mortality is lowest at the optimal eggshell temperature but rises with both temperatures lower or higher than the optimum. In addition, chick quality and early post-hatch growth are affected by the environment in the incubator.

15.4 Overview of Hatcheries

According to the 2018 Hatchery Production Summary by the National Agricultural Statistics Service, average hatchability in the US is 83%. The following are statistics of egg incubation in the US.

- Number of hatcheries in 2018 (see Tables 15.3 and 15.4).
  - Chicken eggs: 292.
  - Turkey eggs: 54.
- Capacity of hatcheries in 2018.
  - Chicken eggs: 951 million eggs.
  - Turkey eggs: 41.1 million eggs.
- Average eggs set per year in 2016.
  - Broiler chickens: 9.21 billion chicks.
  - Broiler pullets: 92.3 million chicks.
  - Layer/pullet type (or egg type): 47.1 million.
  - Turkeys 291 million in 2017

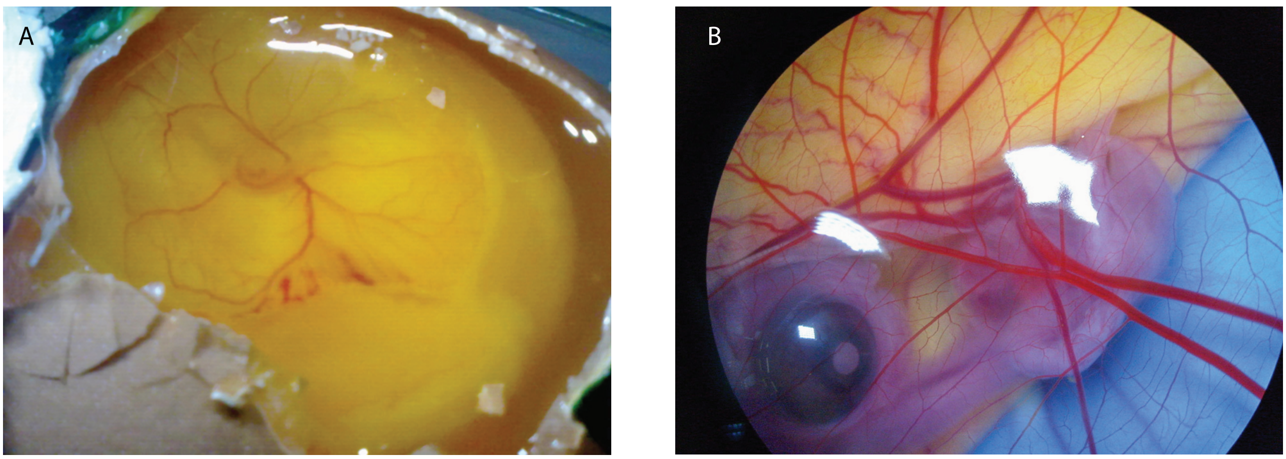


Figure 15.6 A chick embryo after 3 days (A) and 7 days (B) of incubation, showing blood vessels coming close to the air sac. (Sources: L. Gonzalez/Wikimedia Commons [A] and Ben Skála/Wikimedia Commons [B])

TEXTBOX 15B

A Deeper Dive: Impact of Shell Temperature on Embryonic Development

1. **Temperature**: Incubation temperature influences the time required for incubation (Maatjens et al., 2016). As might be expected, time to hatching decreases as temperatures increase. Longer hatching time is associated with slower post-hatch growth (Løtvedt and Jensen, 2014). There are also effects on body weight. In addition, there are effects on the growth of organs based on organ weight relative to body weight. There is, for instance, an inverse relationship between relative heart weight and eggshell temperature. Similarly, incubation temperature has also been shown to influence both villus height and crypt depth in the duodenum (Barri et al., 2011; see Textbox 15B Table 1). A small decrease in incubation temperature is reported to also decrease post-hatching growth (Textbox 15B Table 2) (Joseph et al., 2006).
2. **Carbon dioxide (CO_2)**: The concentration of carbon dioxide (CO_2) in the incubator also has effects on embryonic development (Maatjens et al., 2014a; b). High concentrations of CO_2 leads to poorer chick quality based on navel score, reduced liver glycogen (critical for newly hatched chick to prosper and survive), increased relative heart weight with nutrients diverted to heart growth, and slight alkalosis (Textbox 15B Table 3; Maatjens et al., 2014a; b).
3. **Oxygen (O_2)**: Hypoxia increases embryonic mortality. Hypoxia is also accompanied by reduced relative liver and heart weights on day 20 in large broiler but not small broiler eggs (Lindgren and Altimiras, 2011).

Textbox 15B Table 1 Effect of incubation temperature on development of chick embryos. Data shown is at hatching. Eggs were incubated at a shell temperature of 37.8 °C, some had the shell temperature decreased and others temperature was increased.

Parameter	Decreased 35.6 °C	37.8 °C	Increased 38.9 °C
Temperature changed at d 15			
Time to hatching (hours)	512[b]	491[a]	486[a]
Relative heart weight (%)	0.97[c]	0.72[b]	0.59[a]
Temperature changes at d 15, d 17, and d 19			
Yolk sac free body weight (g)	40.4[b]	39.1[a]	39.5[a]
Residual yolk sac weight (g)	5.7[a]	5.8[a]	6.9[b]
Relative liver weight (%)	2.6[b]	2.5[b]	2.4[a]
Relative stomach weight (%)	5.4[a]	5.7[b]	5.3[a]
Relative intestine weight (%)	3.9[b]	3.7[b]	3.3[a]

[a, b, c] Different superscript letters indicate difference.

Based on Maatjens et al., 2016.

Textbox 15B Table 2 Effect of low incubator temperatures on post hatch growth.

Parameter	Control	Low Temperature
Temperature Incubation d 0–12 (°C)	37.8	36.7
Hatchability (%)	91	87
Body weight (g) d 21	936[b]	891[a]
Body weight (g) d 42	3103[b]	3014[a]

[a, b]Different superscript letters indicate difference.

Data from Joseph et al., 2006.

Textbox 15B Table 3 Effect of carbon dioxide on the development of chick embryos. Data shown is from day 19.

Parameter	0.2% Carbon Dioxide	1.0% Carbon Dioxide
Chick weight (g)	44.3	44.6
Navel score	1.5[a]	1.7[b]
Liver relative weight (%)	2.8	2.7
Liver glycogen (mg)	32.1[b]	24.9[a]
Heart relative weight (%)	0.74[a]	0.79[b]
Blood pH at internal pipping	7.41[b]	7.38[a]
Blood pH after hatching	7.49	7.45

[a, b]Different superscript letters indicate difference.

Based on Maatjens et al., 2014a; b.

Table 15.3 Number of chicken hatcheries in the US.

Year	Number of Hatcheries	Total Egg Capacity (Million)
1975	797	416
2002	322	875
2016	292	930

Table 15.4 Number of turkey hatcheries in the US.

Year	Number of Hatcheries	Total Egg Capacity (Million)
2002	65	47.9
2016	54	41.8

Factoid

The world's largest hatchery is in Hebei, China. This produces 55 million layer chicks per year. It uses Hy-Line layers and uses HatchTech technology. This is equivalent to the entire production in the United States.

Changes in Hatcheries

The major changes in the hatching industry in recent years follow:

- **Fewer and larger hatcheries**. There is a continuing trend for larger hatcheries, where hatcheries with at least 500,000 eggs account for most of the US capacity.
- **Geographical shift**. Hatcheries are located within the geographical area of production. The shift of the broiler industry to the South and South Atlantic states has been accompanied by increased hatcheries in this region.
- **Integration**. Many hatcheries have become a part of a vertical integrated system (owned and operated by the integrator) supplying chicks or poults to growers.
- Reduced labor per million chicks and **increased automation**.
- **Business methods**. Hatchery business is big business that requires excellent management that is well-trained and supervised (see below).
- **Specialized hatcheries**. These supply niche poultry producers, small scale producers, and fanciers. The hatchery may sell chicks via contract and local sales at the hatchery, mail orders direct to customers, and wholesale.

Hatchery Management

The management can make or break any hatchery. Training and supervision of personnel is critically important. Labor requirements include one employee per one million chicks per year and one employee per two million chicks per year if there is automation. **Mechanization** can replace labor for egg grading, candling and transferring of eggs to hatchers, *in ovo* vaccinating, removing debris, and spraying, vaccinating, and boxing chicks.

Indicators for Hatchery Management

- Egg water loss
- Chick yield
- Eggshell temperature
- Infertile eggs and early "deads"
- Hatch debris
- Setter temperature and its variation
- Hatch time and uniformity
- Chick quality (see Section 15.9)
- Chick comfort

Hatchery Sanitation

It is critically important that hatcheries be subject to regular cleaning and disinfection. Moreover, incubators (setters and hatchers) should be cleaned, disinfected, and fumigated, especially prior to the transfer of eggs from setters. All hatching eggs should be sanitized as soon as possible after collection. Fumigation of eggs and incubators is an essential part of a hatchery sanitation program. This can be hazardous and should be done by, or under the supervision of, an experienced and well-trained person.

15.5 On-Farm Handling of Hatching Eggs

Collection of Hatching Eggs

Eggs, to be incubated to produce either chicks or poults, should be collected from the nests four times per day and cooled to temperatures below which development stops. When temperatures are above 85°F

(29.4°C), these eggs should be gathered five or more times a day. Frequent gathering brings the eggs to optimal storage temperatures (see Table 15.5) and reduces the likelihood of contaminating eggs from contact with nesting material and excreta, as well as prevents chilling in winter and overheating in summer. There are considerably more bacteria on floor eggs than nest eggs. It is therefore not surprising that floor eggs have lower hatchability. Nest boxes are cleaned so they do not have excreta, litter, or broken eggs. Moreover, discouraging floor eggs is a priority.

Hatching Egg Management and Cleaning

There should be at least two rooms on a farm: an egg-handling room and an egg storage room. It is best to use only clean eggs for incubation. The number of soiled eggs is reduced by sound management practices such as discouraging floor eggs and cleaning nest boxes. When cleaning soiled eggs, keep the washing water temperature higher than the egg temperature, use a sanitizer-detergent, use a non-recycling washer, and cool the eggs quickly after washing.

Disinfection

To kill bacteria and other microorganisms on the surface, eggs must be disinfected quickly after gathering. Several agents are used. **Antibacterial wipes** are now widely used after egg collection. Approaches to disinfecting the egg room include the following. **Formaldehyde** ($H_2C{=}O$) gas is effective in killing pathogens on shell surfaces but its use is restricted in many countries, including the United States.

The European Union is regulating formaldehyde and alternate methods of disinfecting eggs are being considered. These include **hydrogen peroxide vapor**, **electrolyzed oxidizing water fogging**, **chloride-like products**, and **quaternary ammonium products**. The method, concentration, and duration of fumigation should be in accordance with the manufacturer's instructions and any laws or regulations.

Grading, Storage, and Transportation

Eggs are graded in the egg-handling room, where they are removed if they are cracked, dirty, grossly misshapen (e.g., wrinkled), too small, too large, or double-yolked. On-farm eggs are held in storage rooms. These are thoroughly maintained to remain clean and rodent free. Storage time should be minimized as hatchability decreases with holding time. Temperature and humidity in on-farm holding/storage and transportation are shown in Table 15.5.

15.6 Egg Storage

Fertile eggs are stored at a cool temperature (about 70°F or 21°C) (see Table 15.5). At this temperature, eggs are considered at below physiological zero although there may be some mitotic cell division. Storage for up to 7 days does not influence hatchability. With longer storage times hatchability decreases and early embryonic mortality increases (see Figure 15.7).

Temperature needs to be decreased with extended holding time (see Table 15.5):

- 1 to 6 days: 66.2–69.8°F (19–21°C).
- 7 to 10 days: 64.4–66.2°F (18–19°C).
- 11 days: < 62.6°F (17°C).

Eggs are stored in the farm egg room or hatchery egg room. By cooling eggs, albumen pH increases

Table 15.5 Summary of temperatures at different stages of egg storage and incubation.

Location	Temperature °F (°C)
On farm egg room	70–71 (21.1–21.7)
Egg transport truck	68–73 (20.0–22.8)
Hatchery egg room	66–70 (18.9–21.1)
Pre-heating area	75–80 (23.9–26.7)
Setter	99.5–100 (37.5–37.8)

Based on information from Cobb.

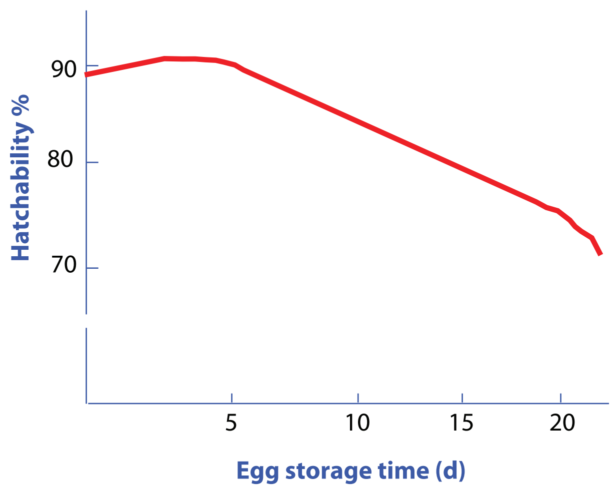


Figure 15.7 Effect of duration of storage on the hatchability of eggs with hatchability declining with extended (based on Aviagen).

TEXTBOX 15C

A Deeper Dive: The Effects of Egg Storage

With prolonged storage of fertilized eggs, there are a series of issues associated with reduced quality, including lower egg weight due to water loss, lower hatchability (see Textbox 15C Table 1), lower chick weight, increase time needed for incubation, shifts in embryo physiology, decreased number of cells in the blastoderm, and a lower proportion of viable cells in the blastoderm (Bakst et al., 2012; Goliomytis et al., 2015; Tona et al., 2003)

Textbox 15C Table 1 Effect of length of storage on eggs from broiler breeders.

	Storage Time	
Parameter	**4 Days**	**16 Days**
Egg weight (g)	59.9[b]	58.4[a]
Hatchability (%)	87.5	80.0
Chick weight (g)	43.8[b]	42.6[a]
Navel score	1.4	1.4

[a,b]Different superscript letters indicate difference.

Data from Goliomytis et al., 2015.

Textbox 15C Table 2 Effect of storage time on chick embryo characteristics.

	Storage Time	
Parameter	**3 Days**	**18 Days**
Timing		
Duration from setting to IP (h)	468[a]	477[b]
Duration of internal pipping (h)	5.3[a]	10.9[b]
Duration of external pipping (h)	12.5	13.8
Other		
Air sac pCO_2 d 18 (mmHg)	40.2[b]	35.3[a]
Circulating CORT at internal pipping (ng/ml)	16.0[b]	13.6[a]
Circulating T_3 at internal pipping (ng/ml)	4.0[b]	3.1[a]

[a, b]Different superscript letters indicate difference.

CORT is the circulating concentration of corticosterone in the chick embryo.

T_3 is the circulating concentration of triiodothyronine (a thyroid hormone) in the chick embryo.

Data from Tona et al., 2003.

Textbox 15C Table 3 Effect of length of storage of eggs on the blastodisc or blastoderm.

	Storage Duration	
Parameter	**3–4 Days**	**10–12 Days**
Cell number (x 10^3)	112.3[b]	55.2[a]
Viable cells (%)	27.3[b]	17.4[a]
Blastodisc diameter (mm)	3.5	3.5

[a, b]Different superscript letters indicate difference.

Data from Bakst et al., 2012.

from 7.5 to 9.0 causing it to liquefy, which aids gas diffusion and nutrient transfer. Short periods of incubation during egg storage (SPIDES) mimics a hen returning to the nest to add a new egg to the clutch. The technique increases hatchability by about 6–7% and reduces incubation time (see Section 15.8).

15.7 INCUBATION (INCUBATOR OPERATION)

Overview

In commercial hatcheries, two separate incubators are used during the incubation process. The bulk of the incubation (up to day 18 or 19) is done in **setters** while the end of the process is in **hatchers**. The main reasons for having setters and hatchers in separate rooms are (1) **sanitation** isolating down, egg debris, and microorganisms that accompany hatching from the eggs in the setter, (2) permitting the hatchers to be cleaned, disinfected, and fumigated without disturbing the eggs in the setters, and (3) the hatchers are equipped with special chick-holding trays, not needed in setters. The following is a schema for the movement of eggs, incubation, and chicks/poults in the hatchery:

[within hatchery holding room] [on farms]

Farm → Setter → Hatcher → Chicks → Brooding

transport transport

There are similar requirements for incubation in either a setter or hatcher, including temperature control, need for ventilation, humidity control, and lighting. These are considered below.

Temperature, Ventilation, Humidity, and Lighting

The ideal temperature for embryonic development is 100°F or 37.8°C. Eggshell temperature is used as a surrogate measure for embryo temperature. The temperature of the air cell is similar to that in the eggshell and embryonic cloaca. As the embryo develops, it takes up oxygen and gives off carbon dioxide. Ventilation in the incubator needs to be adequate to supply oxygen and remove carbon dioxide. The best hatching results are obtained with air concentrations of 21% oxygen and less than 0.5% carbon dioxide. Ventilation removes heat produced by the embryo (see Figure 15.8). The rate of ventilation is increased after hatching as the newly hatched chicks produce much more carbon dioxide. Extraction fans are used to increase air exchange. Humidity should be 70%; this mitigates against excess water loss (see Figure 15.9). Lighting of 12 hours light and 12 hours dark in incubators improves chick quality.

Setting

Eggs should be turned at least 3 to 5 times per day from between day 2 and day 18. This prevents the chorion from adhering to the shell membrane. Turning consists of rotating the eggs back and forth through a 30 to 45° angle. Turning also aids circulation of air in the incubator.

Positioning of eggs is critically important. The embryo head should be in the large end of the egg for proper hatching. Thus, the egg must be incubated large end up (i.e., pointed or small end down) with gravity orienting the embryo with its head up. Between day 15 and day 16 the head of the embryo is near the air cell.

Transfer from Setter to Hatcher

Eggs are transferred from the setter to the hatcher on either day 18 or day 19 of incubation. The transfer must be rapid. During the transfer eggs can be candled and vaccinated by the *in ovo* method. Care should be taken during transfer so that there is no cooling and no eggs get cracked, ruptured, or broken. **Candling** enables identification and subsequent removal (plus counting) of infertile eggs and early mortalities, as well as **rots** and **exploders.** These are eggs contaminated with bacteria that are multiplying rapidly within the egg. Late mortality can occur in the hatcher due to poor positioning or the failure to absorb the yolk sac.

Hatcher

Hatchers are incubators with specific requirements, namely that the eggs are not turned. The hatchers are equipped with special chick-holding trays that are not needed in setters and an increase in ventilation met by extraction fans.

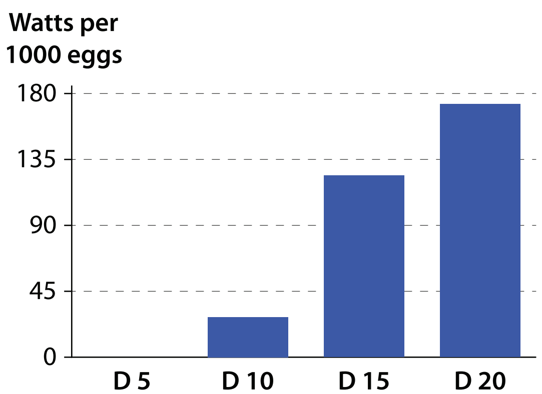


Figure 15.8 Energy production by chick embryos (based on Aviagen).

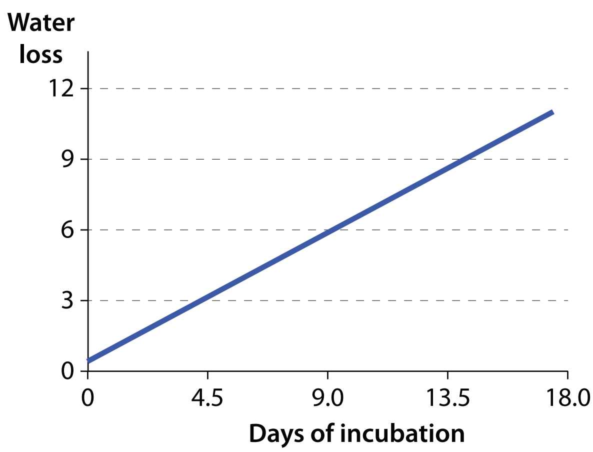


Figure 15.9 Water loss from the embryo (based on Cobb Hatchery Management Guide).

The Embryo Degrades the Eggshell for Hatching

During the second half of incubation there is some degrading of the inner surface of the eggshell due to acidification (CO_2 creates acidic conditions for the solubilization of the shell calcium). The calcium is absorbed into the blood in the embryonic membranes and this calcium passes to the developing bones. Along with the loss of shell calcium, the eggshell becomes more brittle, thus easing the process of hatching.

The Process of Hatching

Day 18: The embryo is positioned with its neck folded and head immediately under the membrane of air space. Such neck folding is maintained after both internal and external pipping and until the chick escapes from the shell once hatching is complete.

Day 19–20: (1) Internal pipping: The embryo becomes active with the head penetrating air sac membrane; (2) External pipping: The shell is penetrated by the egg tooth due to actions of the hatching muscles in the neck; (3) Quiescent period.

Day 20: Hatching. The hole in the shell is enlarged by the beak and egg tooth with actions including back thrusts of the head and rotation of the body.

Embryo Auditory Communication

Eggs in a clutch tend to hatch at about the same time despite different storage times. This is due to special auditory signals transmitted from egg to egg. In chickens, clicking advances the time of hatch. This communication synchronizes hatching time, a feature of considerable survival value in the wild. Slow clicking accelerates development, while fast clicking retards it. Thus, there is communication between embryos—they "talk" to each other. In addition, auditory stimuli influence nervous development.

Incubation of Turkey Eggs

Incubator (or **setter**): 24–25 days.

- Eggshell temperature maintained at 99.4–100°F (37.4–37.8°C).
- Eggs, turned at least three times per day.

Hatcher cabinet: 3–4 days to hatching.

- Eggs, not turned.
- Pipping begins 36 hours before projected removal/pull time.
- Optimal body temperature of poults at pull is 103–104°F (39.4–40.0°C).

Hatchery Building(s)

Certain general requirements of hatchery buildings should always be considered. It is with these that the ensuing discussion will deal. Once buildings are constructed, there is a practical limit to the changes that can be made in remodeling. Consequently, it is most important that very careful consideration be given to the following requisites:

1. **Egg-chick flow through hatchery**. Hatcheries should be designed so that the hatching eggs may be taken in at one end of the building and the chicks removed at the other. Similarly, personnel working in dirty areas should shower and change clothes before entering a clean area, while equipment should undergo washing and disinfecting.
2. **Construction**. The housing of the hatchery building should be constructed of durable material and have good insulation to withstand outside temperature fluctuations and minimize utility costs. Rooms should have well-drained concrete floors conducive to sanitation. The building and surrounding areas should be well lit, kept in good condition, and, hopefully, look attractive.
3. **Rooms**. There should be rooms for separate functions, with clean and dirty areas separated. Hatcheries should be designed so that there are separate rooms for egg receiving, a holding area/hatchery egg room, setter room, hatching room, chick holding room, chick take off, wash room, clean equipment room, hallways arranged with clean and dirty areas, waste storage, employee restrooms with areas for showering and changing, employee break room, manager office, and a standby generator shed.

For temperature, ventilation, and humidity requirements, characteristics of the rooms are summarized in Table 15.6.

Considerations about Hatchery Buildings

- **Egg-chick flow through hatchery**: Hatcheries should be designed so that the hatching eggs may be taken in at one end of the building and the chicks removed from the other.
- **Moveable equipment flow through hatchery**: Equipment should move through dirty corridors to washing rooms and return in clean corridors.
- **Ventilation**: Forced-air circulation is necessary in hatcheries to bring in air and void stale air. There needs to be a back-up generator for ventilation.
- **Heating and cooling**: There needs to be heating and cooling to assure that the temperature and humidity are at the recommended levels (see Table 15.6).
- **Back-up generator**: There needs to be sufficient capacity by back-up generators to supply the incubators and all essential factors.

Table 15.6 Characteristics of a hatchery.

Rooms in Hatchery	Ventilation Rate m^3/hr/1000 (cfm/1000)	Temperature °F (°C)	Relative Humidity %	Pressure vs Atmospheric
Egg receiving	Air exchange[1]	66–70 (19–20)	60–65	0-+
Holding area	3.4 (2)	66–70 (19–20)	60–65	0-+
Setter room	13.5 (8)	76–80 (24–27)	55–62	+
Hatching room	28.7 (17)	76–80 (24–27)	55–62	+
Chick holding room	40 (67.6)	72–75 (22–24)	55–62	0
Chick take off	Air exchange[2]	72–75 (22–24)	65–70	-
Wash room	Air exchange[2]	72–75 (22–24)	65–70	-
Clean equipment room	Air exchange[3]	72–75 (22–24)	N/A	+
Hallways	Air exchange[1]	75 (24)	N/A	-

[1] 5 minute air exchange to room
[2] 0.5 minute air exchange to room
[3] 1 minute air exchange to room

Adapted from Cobb Hatchery Management Guide.

Personnel

Personnel should "shower-in" to the facility and change into uniforms. Workers should stay either on the clean or dirty side of the hatchery (this can be augmented by different color uniforms)

15.8 Other Practices for the Treatment of Eggs

Short Periods of Incubation during Egg Storage (SPIDES)

"Short periods of incubation during egg storage" (SPIDES) is a method to combat the decline in hatchability during storage. Eggs are transferred from the storage room to a working incubator. Eggshell temperatures are brought to above 90°F (32°C) for short periods (3 hours) on one or multiple times. This is effective in increasing hatchability, reducing mortality, and moving the development of the embryo up to Hamilton-Hamburger stage 3 (with 5 periods of incubation).

15.9 Assessment of Chick Quality

It is important to produce high quality chicks. High quality chicks have subsequent good performance—growth, breast size, feed efficiency, and low mortality. In contrast, lower quality chicks have poor performance. Moreover, high quality chicks have high uniformity with the converse also true. Prolonged storage of eggs reduces quality of chicks. Chick quality is assessed by determining the following:

- Visual scoring (~100 chicks). Measures include feather color, navel score, and chick behavior, such as alertness and activity. This is a subjective measure and depends on the person doing the scoring.
- Body weight. This is an objective test but the metric reflects both size of the chick and the yolk sac.
- Yolk-free body weight (~50 chicks). This is an objective test.
- Yield percentage. This is the percentage of chick weight (~60 chicks) to initial egg weight. This is an objective test. The yield percentage is normally about 67%.
- Chick length (~25 chicks). This is an objective test.
- Tona score has been simplified to the Pasgar score. The Pasgar score (~30 chicks) evaluates different criteria such as navel, legs, beak, and yolk sac. These score systems are objective. Objective measures allow comparison between different hatches and different hatcheries. Under the Pasgar score, the numerical quality of chicks is downgraded by the following:
  - — Abnormal reflex behavior. Chicks taking more than 2 seconds to turn to a normal position if placed on their backs.

TEXTBOX 15D

A Deeper Dive: SPIDES

Short periods of incubation during egg storage (SPIDES) improve hatchability compared to stored eggs (Textbox 15D Table 1). There is also reduced incubation time and improved late embryonic development and growth in week 1 (Textbox 15D Table 1). After SPIDES for 6 hours at greater than 98.6°F (37°C), four periods of SPIDES resulted in embryos at Hamilton-Hamburger stage 2, while five periods of SPIDES resulted in embryos at Hamilton-Hamburger stage 3 (Dymond et al., 2013).

Textbox 15D Table 1 Effect of SPIDES (short periods of incubation during egg storage) treatment on hatchability and other incubation parameters and stored eggs.

	Stored	SPIDES	Non-Stored
Hatchability (%)	71[a]	84[b]	92[a]
Incubation time	519[c]	504[a]	511[b]
Early mortality (%)	14[b]	11[b]	4[a]
Late mortality (%)	14[b]	5[a]	3[a]

[a,b]Different superscript letters indicate difference.

Dymond et al., 2013.

There were no changes in the number of cells in blastoderm with SPIDES. There are changes in gene expression with SPIDES:

- **Apoptosis genes**: XIAP (X-linked inhibitor of apoptosis) expression down and CRADD (death domain protein) expression up.
- **Oxidative stress genes**: GPX7 (glutathione peroxidase 7) expression up and SOD2 (super-oxide dismutase 2) expression up.

It may be counterintuitive for there to be changed expression of genes consistent with increased apoptosis (programmed cell death) with SPIDES. Moreover, there is increased expression of genes related to oxidative stress. Superficially, it might be expected that cell death is a "bad thing." However, programmed cell death is one of the essential mechanisms for embryological development. Consequently, an increase in apoptosis would be expected as there is some development of the blastoderm with SPIDES progressing to Hamilton-Hamburger stage 3 (Bakst et al., 2016; Dymond et al., 2013).

— Abnormal navel. For example, navel cloud with either light or black knob, large yolk remnants, open navel, and contamination of the down near the navel.
— Abnormal legs. Swollen and/or malformations.
— Abnormalities with the beak. Malformed, red dot, and/or presence of albumen.
— Yolk. None or yolk sac is very large.

A high-quality chick has a score of 10. One point is deducted for each abnormality. The mean Pasgar score is the average for, say, 30 chicks.

The Navel Score

1 = Completely closed and clean.
2 = Discolored and/or opened < 2 mm.
3 = Discolored and/or opened > 2 mm.

15.10 Treatment of Newly Hatched Chicks

Overview

Hatch window is the time between the hatching of the first to last chick. Ideally, chicks should not be left in the hatcher for more than 24 hours. A goal is to pull 3/4 of the chicks within 12 hours of hatching. If chicks are left in the hatcher for too long, post-hatching performance is depressed. Before pulling chicks from the hatcher, it is important to ensure that their body temperature is at 104°F (40°C). Chicks are removed or pulled from the hatcher when they are dry and their down is fluffed up. If there is a high amount of meconium (waste) residue on the eggshells, this is a sign of either premature hatching or excessive time in the hatcher.

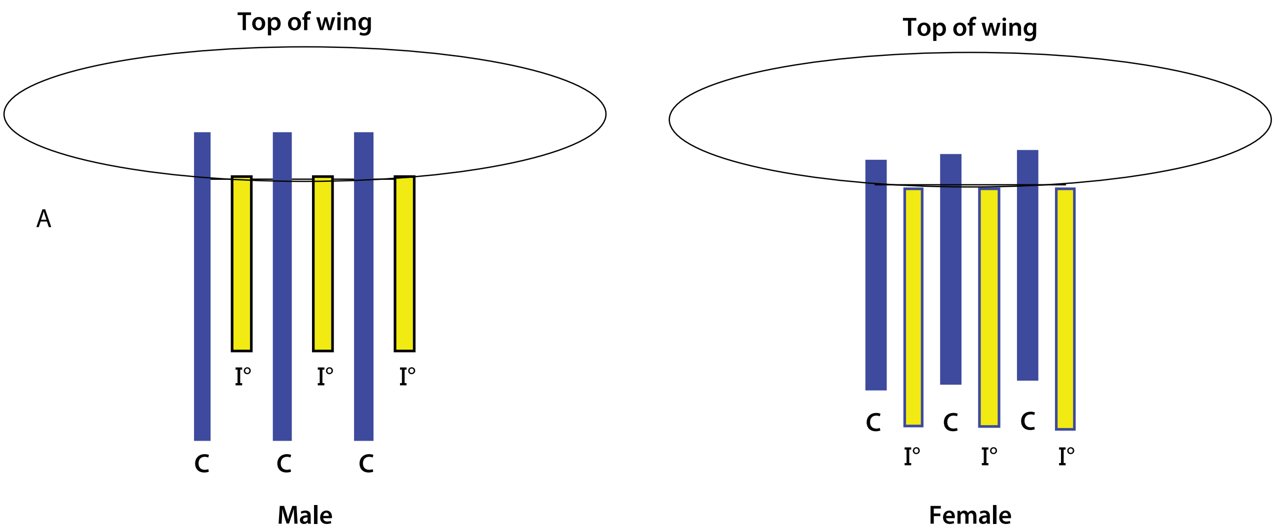
Sexing Chicks

Chick and poult sexing is routinely performed. Male and female broiler chicks can be grown separately or together (straight run). Male and female turkey poults are raised separately. Males of laying lines are not grown for meat because of their low growth rate and poor feed efficiency. Hence, they are killed (with carbon dioxide, for instance) and considered hatchery waste. Chicks and poults are sexed by the following methods.

Sex-Linked Genes

Sex-linked genes for rate of feathering or color pattern are used by breeders to sex day-old chicks. Each method examines either the rate of feathering or down coloring. These two methods of sexing visually follow.

- **Feather sexing**. Day-old chicks can be accurately separated by sex by examining the relative length of the primary and covert feathers of the wing (females carrying genes for fast feathering and the males carrying genes for slow feathering; see Figure 15.10).
- **Color sexing**. Gold and silver genes are used for color sexing at one day old. Gold, buff, or red chicks are females, and white or light-yellow chicks are males.
- **Vent sexing**. Examination of the cloacal wall is widely used by hatcheries to sex newly hatched chicks. The rudimentary copulatory organ (phallus) or male process can be identified at hatching and used to identify male chicks or poults. This method takes skill to be accurate and can be referred to as the Japanese method.



A. Conceptual schema: In males, covert feathers (C) extend beyond primary feathers (I°). In females, primary feathers (I°) extend markedly beyond covert feathers (C).

B. Feathering on the wing showing shorter primary feathers in males than females in comparison with covert feathers. (Photo courtesy of Dr. Jacqueline Jacob, University of Kentucky Extension)

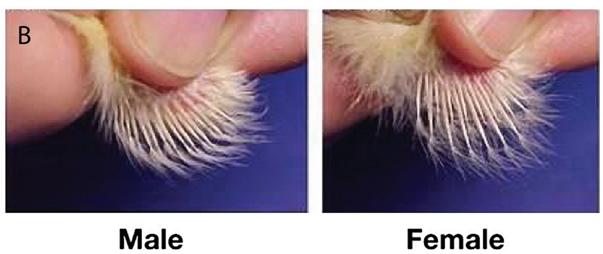


Figure 15.10 Feathering, and specifically the sex-linked fast-feathering gene (recessive), can be used for sexing. When a rapid-feathering male (sex chromosomes WW) is crossed with a slow-feathering female (sex chromosomes WZ), males and females have respectively short and long primary feathers.

Beak Trimming (Conditioning) and Vaccination

Beak trimming of day-old broiler chicks, replacement pullet chicks, or turkey poults is performed by hatcheries. This improves welfare as it reduces feather pecking. The immunity passed to chicks from the egg protects them for the first few weeks of life and often makes vaccination ineffective. For this reason, most vaccines are administered after chicks have left the hatchery and after maternal antibodies have dropped to low levels. There is one exception: hatcheries vaccinate either day-old chicks or *in ovo* for Marek's disease.

Transporting Chicks and Poults

In commercial poultry operations, chicks and poults are transported from the hatchery to the growers for broiler chicks, turkeys, or pullets. They are transported at the required temperature in cardboard or cleaned plastic boxes. Particularly, with broiler chicks, hatcheries deliver the chicks expeditiously after hatching and at a scheduled time. This facilitates getting them on feed and water quickly to reduce early mortality and improve growth. It is important that they are not overheated or chilled during shipment. Chicks may be transported for up to two days without feed or water (except what comes from the yolk) and still arrive in good condition.

Brooding

Brooding is the care of chicks and poults from the time received from the hatchery. This is a critical phase of the poultry business and is covered in Chapter 8. Success in brooding for pullet chicks is indicated by a uniform flock of fast-growing, well-feathered, healthy pullets and ultimately good layers. Success in brooding for broiler chicks and turkey poults results in rapid and uniform growth, high efficiency of feed utilization and low rates of mortality.

15.11 Waste Disposal

Hatcheries have wastes including infertile eggs, eggshells containing membranes, eggs with dead embryos, and sexed male chicks. Eggs remaining in the hatchery are macerated to kill any unhatched embryos and chicks are killed with CO_2 or another acceptable method. Methods of disposal include incineration, landfill, composting, separation into liquids (going to pet food) and solids (landfilled), and a hatchery by-product meal following rendering.

As mentioned earlier, rots and exploders are eggs contaminated with bacteria that are multiplying rapidly. These eggs have to be disposed of in a specific way—by placing them into disinfectant. Incineration is an effective means of disposal of hatchery waste, meeting needs for sanitation and disease control. There are costs such as propane or natural gas. Moreover, it is unprofitable. Hatcheries also can process hatchery waste into a component of livestock feeds. This is known as hatchery by-product or **hatchery by-product meal**. Hatchery by-product meal is high in protein (33% crude protein in dried meal) and calcium but cannot be used in animal feed in some countries.

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Approaches Common to Different Poultry Types

16

Biosecurity, Brooding, Litter, Water Quality, Pests, and Beak Conditioning

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Define biosecurity.
2. Explain if a biosecurity plan should be voluntary or mandatory and provide reasons for your answer.
3. Name four important aspects of a biosecurity plan.
4. Explain why brooding is important.
5. Name three critical features of successful brooding.
6. Explain what litter is and if it can be reused.
7. Know what is done with spent litter.
8. Explain why broiler chickens, turkeys, and some laying hens are placed on litter.
9. Know the effects of poor litter conditions.
10. Know where water for poultry should be obtained.
11. Explain how you can be assured that water is of sufficient quality.
12. Explain the problems associated with rodents, flies, and beetles in and around poultry facilities and why controlling them is important.
13. List the components of rodent control programs.
14. List major rodenticides.
15. Explain how beak conditioning is accomplished and why it is performed.

16.1 Overview of Management Approaches Common to Different Poultry

Table 16.1 summarizes the important aspects of stockmanship. This chapter focuses on a series of techniques applied to broiler chickens, layer chickens, and turkeys. Other general management approaches are considered in dedicated chapters. This includes topics such as incubation (see Chapter 15), poultry houses and equipment (see Chapter 17), and poultry waste (see Chapter 11). Techniques that are specific to segments of poultry production include induced molting for laying hens (Chapter 18) and specific approaches for broiler production (Chapter 19) and turkey production (Chapter 20).

16.2 Biosecurity

Biosecurity is essential for poultry irrespective of whether in a commercial production facility, a research environment, a teaching facility, or a backyard flock. This is to minimize risks of diseases coming from pathogens such as *Salmonella*, *Mycoplasma*, avian influenza (AI) viruses, or other infectious agents.

Table 16.1 Importance of stockmanship.

Sense	Actions Include
Sight	Observing bird distribution, feeding, drinking, resting, and panting. Are the eyes clear? Is the gait normal? Are there wounds or discoloration? Is the vent clean? Check litter condition, temperature, ventilation, and water consumption.
Smell	Assuring the absence of ammonia and air stuffiness.
Taste	Assuring water and feed quality.
Touch	Determining crop fill, poultry house temperature, and pressure in unit by ease of opening door (pressure).
Hearing	Are bird vocalizations and respiratory sounds normal? Are fans operating normally? Are augers working continuously?
Brain	Engaged!

Adapted from Aviagen, 2018.

Table 16.2 Key features of a biosecurity program.

Key Components

1. Mandatory
2. Practical (and effective)
3. Cost effective
4. Part of staff training programs
5. Reviewed regularly
6. Committed to by the whole company and staff
7. Financially resourced

Figure 16.1 Disinfectant used to spray boots, trucks, and other equipment as part of a biosecurity plan. (Source: Eric Buermeyer/Shutterstock)

Wild migratory birds, particularly waterfowl such as ducks, are reservoirs for many poultry pathogens. A source of many highly infectious pathogens that infect poultry is wild birds. Pathogens can be spread by other means, such as moved vehicles or equipment or dead birds when these are contaminated with pathogens, aerosol droplets and dust particles contaminated with pathogens from infected or dead birds, and people inadvertently carrying pathogens, such as on contaminated clothing.

Proximity (closeness) is critical to spreading pathogens. This closeness applies to physical distance and to any shared inputs (staff, equipment, vehicles, etc.) between and among different commercial facilities and commercial facilities and other sites where poultry are held (such as backyard poultry). With closer proximity, the biosecurity plans must be even more rigorous. Table 16.2 summarizes some of the critical features of biosecurity.

According to the United States Department of Agriculture's Animal and Plant Health Inspection Service (USDA APHIS), biosecurity is considered as structural and operational. Among the practices recommended by APHIS to assure biosecurity are the following:

- A biosecurity plan must be in place.
  - There should be standard operating procedures encompassing cleaning and disinfection of equipment and buildings (see Figure 16.1).
  - Personnel should be provided with protective clothing.
  - Boot-washing should be installed and maintained.
  - There must be quarantine procedures.
  - Access to the facility should be limited with a perimeter fence and marked with proper signage (see Figure 16.2).
  - There should be a buffer area and a line of separation between buildings.
  - In the event of an outbreak, arrangement should be in place for (1) shut-down of ventilation to prevent the spread of pathogens and (2) depopulation.
- Each poultry facility or company should have a biosecurity officer.
- There should be regular biosecurity training for all personnel.

Figure 16.2 A biosecurity sign alerting prospective visitors not to proceed. (Source: Eric Buermeyer/ Shutterstock)

- It is recommended that all personnel shower and change into clean clothes and be disinfected before entering a poultry unit and before moving between units.
- Biosecurity control measures must be in place to protect poultry from pathogens that can be carried by wild birds, rodents, and insects.
- There should be thorough cleaning and disinfection of equipment.
- It is not advisable to share equipment between different units.
- Birds should come from flocks certified free of primary poultry diseases.
- Vehicles for transportation of birds should be completely cleaned and disinfected between uses.
- Water should be tested and treated where necessary.
- Feed and litter must be stored and handled to prevent contamination with pathogens, e.g., from wild birds or rodents.
- Ensure that plans are in place for depopulation in the event of an outbreak.
- In the event of a possible disease outbreak, inform regulatory and other animal health professionals immediately.

TEXTBOX 16A

A Deeper Dive: Biosecurity with Backyard Poultry

Based on a study in Colorado, biosecurity in backyard flocks is viewed as of low importance / priority by backyard flock owners (Smith et al., 2012). Cases of avian influenza have been confirmed in wild waterfowl and backyard poultry (Martin et al., 2015). Similarly in Greater London, owners of backyard poultry exhibit a lack of even rudimentary knowledge of biosecurity (Karabozhilova et al., 2012). Backyard chicken owners in the United States have a relatively low concern for biosecurity, with most allowing visitors who do not wear different shoes or clothing when entering the poultry areas, and allowing interaction of their birds with wild birds (Elkhoraibi et al., 2014). The issue of biosecurity with backyard flocks is accentuated by their being on average 1.9 backyard flocks within a mile radius of commercial poultry operations (Garber et al., 2007). There is a marked tendency for backyard flocks to seropositive to avian influenza (AI) if they are exposed to waterfowl (Madsen et al., 2013).

16.3 Brooding

Brooding is essential for the successful growth of day-old broiler chicks and turkey poults, together with chicks to be reared as replacement pullets. The first issue is chick or poult quality.

Importance of Chick Quality

Chick quality is critical to broiler performance and is related to the absence of remaining membranes, retained yolk, neurological abnormalities, and small size.

Critical issues for brooding are temperature, water availability, feed availability, adequate space and secure environment, regular inspection by personnel, and personnel training. Brooding has become increasingly important as the period of brooding has made up a greater proportion of the time to market weight and it positions the chick or poult to achieve its genetic potential for growth. Brooding attempts to have an ideal environment for the chicks or poults such that they are active, eating, and drinking. The brooding environment should not stress the chicks or poults. Examples of stresses to avoid include the feed or water being too far from the chicks or poults, being too warm or too cool, and the environment being too drafty.

Temperature Control

There are optimum temperatures for chicks and poults at different ages (see Tables 16.3 and 16.4). A reliable thermometer will enable the caretaker to ensure comfortable temperatures. If in doubt, however, the chicks will tell you (see Figure 16.3). If the chicks huddle or crowd together and cheep (vocalize), they are too cold. If the chicks move away from the source of heat or from under the brooder, or if they pant and hold their wings away from their bodies, they are too warm. Chilling chicks may result in piling and smothering. Temperatures too cool will also cause diarrhea and increase susceptibility to infectious disease, together with reducing growth rate. Temperatures too warm result in reduced appetite and retarded growth.

Ventilation and Moisture Control

Ventilation is required to provide fresh air for the chicks and to remove ammonia, carbon dioxide, and carbon monoxide, together with water vapor to keep the litter dry. Gas, oil, and other flame-type brooders that burn the oxygen out of the air require more ventilation than other types of brooders. A good ventilating system provides plenty of fresh air without drafts. Chicks huddling in certain areas or spots may indicate floor drafts. A strong odor of ammonia means that there is not enough air movement. If the floor litter is relatively dry and the air in the house has little or no ammonia or other odors, this is an indication that the ventilation is adequate. A fairly humid environment, around 50 to 60% relative humidity, is desirable initially.

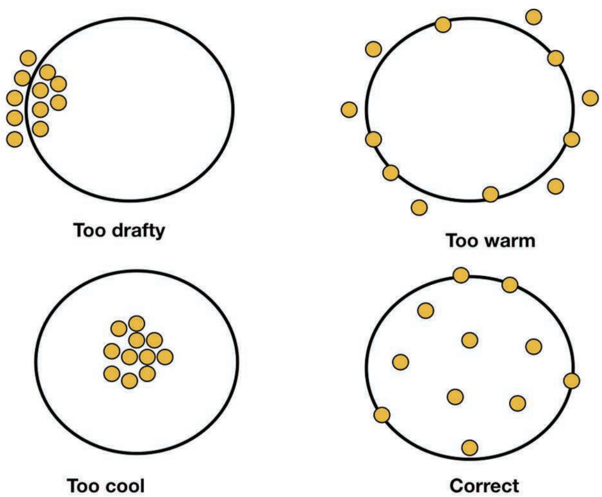


Figure 16.3 Chick behavior under different brooding conditions/temperatures. The "goldilocks effect" refers to temperatures needing to be just right.

Brooder Houses and Equipment

In commercial production, chicks are reared in brooder houses with 50,000 or more birds brooded as a unit and cared for by one person. Common features for brooding include the following (also see Figures 16.4 and 16.5):

- For spot brooding: a brooder guard enclosing chicks or poults and heaters or stoves (pancake [jet] brooders, infrared [radiant] gas brooders, or forced-air furnaces).
- Supplemental waterers or mini-drinkers in addition to the automatic water (nipple) line.
- Supplemental feeders and feed spread on the paper.
- Litter covered with paper for secure footing.
- Good ventilation to prevent buildup of toxic gases including ammonia.

When Can Young Chicks or Poults Thermoregulate?

The ability of young birds (chicks and poults) to thermoregulate and hence achieve a consistent body temperature is not fully developed until about 12 days old.

Management Schedule

Successful brooding requires a well-programmed and well-executed management schedule. The following management schedule is divided into five parts: (1) preparation for the chicks or poults, (2) before the chicks or poults arrive, (3) transportation, (4) when chicks arrive, and (5) after the chicks are placed.

Preparation for the Chicks or Poults

- Clean thoroughly. Thoroughly clean the poultry house (floor, walls, and overhead) and the equipment, including drinkers and water lines.
- Disinfect. Disinfect the brooder house, using one of the commercial disinfectant materials according to the manufacturer's directions. For the disinfectant to be most effective, the brooder house must first be thoroughly cleaned.

Table 16.3 Brooder and brooder house temperatures for broiler chicks.

Age (Days)	Brooder House Temp °F (°C)	Spot Brooding Temp °F (°C)	
		Brooder Edge Temp	Temperature 2 Meters (6.5 feet) from Brooder Edge
1	86 (30)	90 (32)	84 (19)
3	82 (28)	86 (30)	81 (27)
6	81 (27)	82 (28)	77 (25)
9	79 (26)	81 (27)	77 (25)
12	77 (25)	79 (26)	77 (25)
15	75 (24)	77 (25)	75 (24)
18	73 (23)	75 (24)	75 (24)
21	72 (22)	73 (23)	73 (23)
24	70 (21)	72 (22)	72 (22)
27	68 (20)	68 (20)	68 (20)

Based on Aviagen.

- Check all equipment including the brooder and other heat sources, ventilation system, and environmental alarms 2 or 3 days before the chicks arrive to make sure they are properly adjusted and working satisfactorily.
- Clean, fresh litter. Clean litter should be spread to a depth of 2–4 in. (5–10 cm). In the brooding area (surrounded by cardboard rings or guards), it is critical that the litter be level. (For chicks, place paper over 80% of area; for poults, compact the litter). Insufficient litter does not provide adequate insulation or moisture absorption.
- If using spot brooders, install brooder guards. If brooder guards are used, place cardboard brooder guard rings with a diameter of 12–14 ft (3.7–4.2 m) and a height of 18 in. (45 cm). This guard will keep the chicks confined to the brooder area and result in their eating and drinking faster.
- Waterers. There should be nipple lines (12 birds per nipple), bell drinkers (6 drinkers per 1,000 chicks), and supplementary drinkers (e.g., 10 mini-drinkers per 1,000 chicks) (see Figures 16.4 and 16.5).
- Rodent and insect control programs need to be checked.

Before the Chicks or Poults Arrive

- Pre-heat to target house, floor, and litter temperatures 24 hours before placement (see Tables 16.3 and 16.4 for temperatures for broiler chicks and turkey poults, respectively) and ensure a relative humidity of 60–70%.

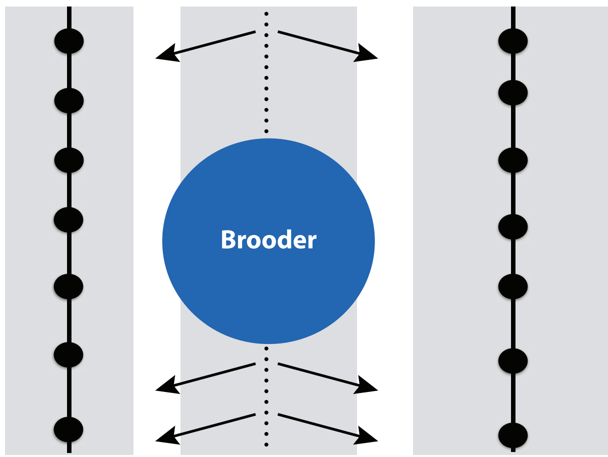


Figure 16.4 A schematic of spot brooding (for whole house the scheme is the same but there is no spot brooder). The solid lines with black spots are automatic pan feeders, the dotted line in the middle are the nipple drinkers, the arrow lines are supplementary drinkers, and the grey background (markspaper) covers 80% of areas (based on an Aviagen schematic).

Table 16.4 Brooder and brooder house temperatures for turkey poults.

Location/Time	Temperature °F (°C)
Beneath brooder	
Immediately beneath	100–105 (38–40)
Close to edge of brooder (1 ft or 0.3 m from edge)	88–92 (31–33)
Edge of brooder ring	78–82 (26–28)
Brooder house	
Week 1	82 (28)
Week 2	80 (27)
Week 3	78 (26)
Week 4	74 (23)
Week 5	72 (22)
Week 6	70 (21)
Week 7	68 (20)
Week 8	69 (19)

Based on Aviagen turkeys.

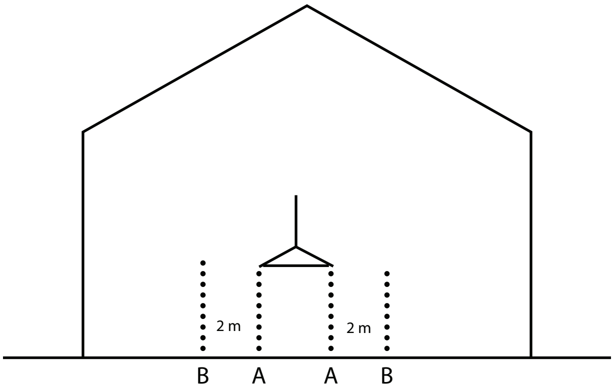


Figure 16.5 A schematic showing the position of the brooder in the poultry house. (A) marks the brooder edge and (B) marks 2 meters (6 1/2 feet) from the brooder edge (based on an Aviagen schematic).

- Fill supplementary feeders with textured feed.
- Start lighting program with a photoperiod of 23 hours of light and 1 hour of darkness per day (23L:1D) for 7 days (see Table 16.5).
- Have the delivery time scheduled such that crew are ready to place birds.

Transportation

- Transportation of young birds should be in suitably equipped trucks with chicks maintained at 71.6 to 81.4°F (22 to 28°C), with a relative humidity (RH) of at least 50–65% and with ventilation of 0.71 m^3 per min (25 cfm or cubic feet per minute) per 1000 chicks. This ensures that the air immediately around the chicks or poults is at 86–95°F (30–35°C) with a RH of 70–80%.
- Chick vent temperatures should be 103 to 105°F (39.4 to 40.5°C) during chick holding at the hatchery, transportation, and the first 4 or 5 days of brooding.

After Chicks Arrive

- Chicks and poults should be placed in brooder areas as soon as possible after hatching.
- Placement and handling of the young birds should be done quickly and gently.
- Feeding. As appropriate for broiler chicks, broiler breeders, replacement pullets, turkeys, and so on.
- Water. Plenty of clean, fresh water should be provided at all times. Water should be distributed so that the chicks or poults can drink conveniently.

Table 16.5 Lighting for chicks and poults.

	Chicks	Poults
Photoperiod	23L:1D	23L:1D
Light Intensity of Photophase (day)	30–40 lux [3–4 foot candles (fc)]	25 lux [2.5 fc]
Light Intensity of Scotophase (night)	< 0.04 fc (0.4 lux)	< 0.04 fc (0.4 lux)

- It is recommended that the weights of between 50 and 100 chicks or poults in a poultry unit be recorded and the mean body weight and uniformity be determined.

Definitions

Mean body weight: The average weight. It is calculated by adding the body weights together to get the sum and then dividing the sum by the number of observations.

Uniformity: Assessed by the coefficient of variation (CV) as expressed as a percentage. The higher the CV, the lower the uniformity.

Coefficient of variation (CV): The standard deviation (SD) divided by the mean and multiplied by 100.

$$\text{Coefficient of variation (CV)} = \frac{\text{Standard deviation (SD)} \times 100}{\text{Mean}}$$

Standard deviation (SD or sigma or σ): Can be readily calculated on an Excel spreadsheet. At a deeper level, standard deviation is

$$\sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \mu)^2}$$

where √ is square root, N is the number of observations, Σ is the sum of, x_i are the observations (x_i is x_1, x_2, x_3, etc., where x_1 is the first observation, x_2 is the first observation, x_3 is the first observation), and μ is the mean.

After Chicks or Poults are Placed

- Observe the chicks or poults to make sure that they can reach and are reaching the feed and water after a settling period.
- Check feeders and add additional feed.
- Remove chick or poult boxes immediately.
- Assure the desired temperatures are achieved by determining temperature and observing the chicks or poults (see Figure 16.3)

- Remove brooder rings. For chicks, brooding rings are expanded beginning on day 3 and completely removed by days 5–7. For turkey poults, open the rings after 7–10 days.
- Are feeders and waterers crowded? If so, there is not enough space.
- Is the litter packed and wet? If so, improve the ventilation and/or put down new litter.
- Is there a strong ammonia odor? If so, improve ventilation and/or change litter.
- Mortality and on-farm condemnations. If so, there are significant problems that need to be addressed.
- An unsteady or awkward gait. If so, there are significant problems that need to be addressed.

Indicators of chick or poult comfort include the following:

- The distribution of chicks or poults in the brooder.
- Crop fill. This should be between 80 and 85% 12 hours after placement and 95–100% after 24 hours. This demonstrates that the chicks or poults are in their comfort zone and are successfully searching for feed and water and are both feeding and drinking.
- Vent temperature by thermal scanning about 103°F (39.4°C). If the vent temperature is below 101°F (38.3°C), chicks or poults are probably too cool. If the vent temperature is above 105°F (40.6°C) chicks or poults are probably too warm.

The Crop: Its Anatomy and Function

The crop is a sac-like organ at the end of the esophagus and just before the proventriculus and gizzard. The crop is expandable and stores feed on a short-term basis. The feed then passes to the proventriculus and gizzard (see Figure 4.16 in Chapter 4).

Health, Vaccination Status, and Nutrition of the Breeders

The health of chicks or poults is critical to their development to market weight. During embryonic development, birds receive nutrients for the egg yolk and white (together with some calcium from the shell). Nutrient deficiencies in the breeders will result in deficiencies in the egg. An example of an important nutrient is linoleic acid. Developing chicks or poults receive antibodies from their mothers (passive immunity). Thus, vaccination of the hens is critical to chick and poult development. Furthermore, breeder birds should be free of important pathogens, such as all species of *Salmonella*, *Mycoplasma synoviae*, and *M. gallisepticum*.

Uniformity of Chicks or Poults

Chick uniformity is important as poultry units are arranged on the basis of the average chick or poult. For instance, the heights of the feeders and drinkers are set based on the average. This means that small chicks or poults will have difficulty reaching feed or water.

Problems with Chick or Poult Uniformity

There can be problems when a hatchery is mixing eggs from birds at different stages of lay. The eggs from breeders at the beginning of lay are smaller. This leads to small chicks as chick weight is 65–68% of egg weight. Chicks from small eggs should be handled separately. Another issue is if breeds are mixed at the hatchery as they have different growth curves.

16.4 Litter

Litter is used primarily for the purposes of keeping the birds clean and comfortable. It absorbs moisture from the droppings and then loses this moisture to the air brought in by ventilation. Excreta accumulates in the litter and begins to break down.

The floors of broiler houses are covered with litter to a depth of 5–10 cm (2–4 in). Exceptions to this are materials with relatively poor water absorbency such as rice hulls, peanut hulls, and coconut husks. In this case, the depth should be greater (8–10 cm/3–4 in). Another exception is when temperatures are adequate (> 82–86°F/28–30°C) when the depth can be 5 cm (2 in). Litter is essential for the welfare of the growing broiler chickens. Litter must be purchased from a reliable biosecure source. It is also important that the litter be free of noxious contaminants.

Litter management seeks to reduce or eliminate wet litter and dust. The advantages of litter are bird comfort, absorption of moisture to improve the health of the birds, and biodegradability. The preferred sources of litters in many areas of the United States are pine shavings, sawdust, and rice hulls. These are available in broiler-producing areas and help to provide litter with optimal levels of moisture. Alternative sources of litter are the following:

- Chipped pine or hardwood bark.
- Chopped straw or hay. The disadvantages of this for litter include both risks of caking and mold growth.

- Coconut husks. However, these are not generally available at a reasonable cost.
- Crushed corn cobs. These are not generally available. In addition, there is an increased risk of breast blisters.
- Flax straw. This is not generally available at a reasonable cost.
- Hardwood shavings and sawdust. A disadvantage is that the litter tends to have high moisture and consequently mold may be growing.
- Peanut hulls. These are not generally available and have a susceptibility to mold growth.
- Peat moss. Disadvantages include cost and availability.
- Pine or hardwood chips. Broiler chickens raised on litter composed of these chips have an increased risk of breast blisters.
- Processed paper. Use of this for litter increases the risk of the litter caking. It is difficult to manage litter from processed paper in areas where there is high humidity.
- Sand. Disadvantages are that it requires good management, due to the susceptibility of retaining water and the difficulty in assuring optimal floor temperature, and concrete floors.
- Straw pellets or chemically treated straw pellets. The litter produced from the former tends to have high moisture.

It is important that the litter not be too dry as this will be accompanied by dust. High levels of dust pose health risks to the birds and the workers in the house. Moreover, litter should not be too wet. Problems associated with wet or inadequate amounts of litter are dirty footpads, footpad dermatitis, hock burns, and increased ammonia generation with adverse effects on bird health.

The amount of moisture in the litter is increased under the following conditions: winter, reduced ventilation, the number of drinkers, and the distance from heaters. Litter can be removed after harvesting the flock. If litter can be re-used (common practice), there are risks of the transfer of pathogens from one flock to another. To reduce this risk, fresh litter can be added in a management process known as "top-dressing."

Treatment of Used Litter

After harvesting flocks, the poultry houses are cleaned and the used litter may be taken out. Prior to removal of the used litter, a detergent solution is sprayed throughout the house to reduce dust. All the litter is removed mechanically using skids or mini-backhoes. The exhausted litter is immediately placed into large walled containers such as trailers or dumpsters in or close to the poultry house. In order to assure biosecurity, the following are required:

- When the container is filled, it should be covered to prevent wind movement of dust, etc.
- Equipment used to clear the poultry house and move used litter must be cleaned and disinfected.
- Filled containers must be moved at least 2 miles (3.2 km) from the poultry house.

How Used Litter Should Be Treated

Litter disposal is addressed in detail in Chapter 11. It must follow all appropriate federal, state, country, and local rules and regulations. In brief, spent litter can be land applied to arable crop land at least 3.2 km (2 miles) away from the poultry facility, composted and then applied to areas used for livestock grazing, used for biofuel to generate heat or buried in landfill or quarry, etc. Biosecurity must never be compromised. Spent litter should not to be stored within 3.2 km (2 miles) of the poultry house(s). This is again for biosecurity. Ventilation is covered in Chapter 17.

TEXTBOX 16B

A Deeper Dive: The Impact of Poor Litter Conditions

What do poor litter conditions cost for a flock of 100,000 birds? The University of Georgia Extension Service estimates that costs of poor litter per flock are as follows:

- Ammonia: $2150
- Disease: $600
- Parasites: $700
- Condemnations and downgrades: $1300

Total: $4750. If there are six flocks per year, losses rise to $28,500.

Litter conditions are very important. As they grow, chickens are releasing large amounts of water in the expired air (in every breath) together with some also in feces and urine. This water adds moisture to the litter and can then lead to an increase in the release of ammonia (discussed in detail in Chapter 17). Wet litter has negative consequences on the chickens with increases of breast blisters, bruising, condemnations, and downgrades. Ventilation removes much of the water vapor from the air.

16.5 Water and Water Quality

Poultry require considerable quantities of water. There are two sources of water: (1) water intake or consumption and (2) metabolic water.

Water Consumption

The water requirements of broiler chickens are the following:

- About 6–7 liters of water removed from drinkers per bird during the period of growth of broiler chickens to 49 days. This reflects consumption together with some spillage.
- The ratio of feed: water intake by broiler chickens is 1:1.77 (1:1.6–1:2.0)
- Water consumption increases with age during broiler growth.
- There is greater consumption with higher environmental temperatures.

Note: the quality of the water is important to optimal performance.

Water Quality Plan

This should include the following:

- Knowledge of the source of water. Is it city/running/municipal water or piped from deep wells?
- Testing water should be done regularly but with an increased frequency during droughts and heavy rainfalls.
- Water may be contaminated with pathogens, pesticides, or metals such as iron. Contaminants such as iron adversely affect the water lines and fogging systems. Moreover, some contaminants can impact the health of birds.
- Based on testing, it can be advisable to filter the water. In addition, if water is being filtered, it is important to both inspect the filters for clogging due to iron and change filters on a regular basis and following manufacturer's recommendations.
- Water lines should be flushed with high pressure to remove biofilms of bacteria including pathogens and any supplements. It is essential that there are not airlocks in the water lines.

Additional issues to be monitored in the water system include waterers at the incorrect height for the size of the birds, incorrect water line pressure, clogged drinkers, leaky nipples—loss of water and reducing litter quality, and too many birds per drinker.

Water consumption figures can also be used as an indicator of the health of the flock. Water consumption should be increasing with the age of the broiler flock. This is because as the birds get bigger they consume more water. If water consumption is not increasing, this is an indicator of a problem.

16.6 Controlling Pests

The necessity of getting the greatest production per bird and the most profitability requires the timely use of pesticides to control insects (flies, beetles, fleas, and lice), other arthropods (mites), rodents, birds, and other pests. At the same time, the producer must be increasingly concerned about timing, choice, and dosage of registered pesticides, along with the method of application, in order to stay within the residue tolerances or limits allowed in eggs and meat by the Food and Drug Administration. Government agencies are continually sampling eggs and fowl for pesticide residues, feed additives, and antibiotics. Misuse of these chemicals can result in financial loss through confiscation and reflect discredit on the poultry industry. For pesticides to be used properly and efficiently, the following precautions and suggestions should be observed:

- Good sanitation and regular inspection of buildings and birds.
- Start using pesticides early. Pest control methods should be instituted before the problem builds up and reduces production efficiency.
- Use only approved pesticides. Only registered, approved pesticides should be used on birds, in and around poultry houses, in egg rooms, or in storage areas. New products are developed, and sometimes old products are banned. Accordingly, it is recommended that the producer follow the current recommendations of the Cooperative Extension Service, or other recognized specialists, for the control of pests.
- The operator should read and follow the label directions.
- Mix and use pesticides with care. Pesticides should be mixed where birds cannot get to containers, equipment, or spillage. Likewise, pesticides should be kept away from eggs, feed, feeders, water, and watering equipment. Good ventilation should be provided in confined areas.
- Pesticides and application equipment should be stored in a separate, marked, locked building or

storage area away from children, poultry, feed, and water sources.

- Dispose of empty paper and plastic containers in an approved manner. If burned then the ashes should be buried.

16.7 Rodents

Poor sanitation attracts rodents. Poor management allows them to stay and their population to grow. The major rodents that infest poultry houses and the areas around them are the brown rat (*Rattus norvegicus*), black rat (*Rattus rattus*), and house mouse *(Mus musculus*). In addition, the Polynesian or Pacific rat (*Rattus exulans*) is found in Hawaii and other islands in the Pacific Ocean, Southeast Asia, and New Guinea. It is thought that the Pacific rat was distributed by Polynesian settlers.

Rodents have severe negative consequences for poultry production due to the following:

- Consumption of feed (100 rats consume ~1 ton of feed per year).
- Contamination of feed with feces and urine.
- Spreading of diseases to poultry and zoonotic diseases to people. Rats and mice are sources and reservoirs of pathogens for poultry, both viral (e.g., fowlpox and fowl cholera) and bacterial (e.g., *Bordetella, Leptospira, Salmonella,* and *Streptococcus*). The pathogens may be transmitted from rodent feces or their external parasites.
- Damage to buildings. Rodents can undermine building foundations, gnaw electrical lines, destroy insulation (this is a frequent site for rodents to live), and chew through wood, rubber, vinyl, etc.
- For free-range poultry, rodents may attract predators such as foxes and coyotes.
- Rapid reproduction of a female mouse, capable of producing 35 to 60 offspring in a year, which are in turn sexually mature in about 7 weeks. Rats have a similar fecundity.
- Attacks on young poultry, damage to eggs, etc.
- Being a nuisance to neighbors.

Rats tend to eat grain at a limited number of locations while mice are less restrictive. Rats also need a source of water. These rodents are predominantly nocturnal. Seeing them during the day suggests that there are high populations.

Observation of Rodents

Signs of rodents include the following:

- Droppings. Each night mice produce about 70 droppings and rats produce about 35 droppings. Rat droppings are about 0.5 to 0.75 inches (1.3 to 1.9 cm) long while mouse droppings are about 0.25 inches (0.6 cm) long.
- Gnawed holes in wood and electrical wiring.
- Urine stains that fluoresce under black (UV) light.
- Rodent holes/burrows.
- Numbers caught as part of a rodent control program.
- Numbers observed.

Control of Rodents

The rapid rate of reproduction and the destructive power of rodents, together with concerns for poultry health, make rodent control essential. Moreover, rodents eat the poultry feed and consequently reduce feed to gain ratios. The success of these efforts should be monitored. This should be coupled with good recordkeeping. Approaches used to control rodent populations include the following:

- Physical exclusion from facilities and feed (rodent proofing).
- Rodenticides.
- Fumigation between flocks.
- Trapping (snap traps, glue boards, called "sticky traps," and humane traps).
- Maintain the walls and concrete floor of the poultry house such that there are not cracks or holes through which rodents can enter.
- Maintaining areas around poultry houses as clean and free of debris or disused equipment with grass and other vegetation cut back. These are areas where rodents can nest. A clean 3 ft (1.0 m) perimeter not only looks good but also allows detection of rodents and their burrows. An alternative is a heavy gravel perimeter (2 ft wide and 0.5 ft deep).

These approaches need to be coupled with good recordkeeping. An example of where to bait with rodenticides is shown in Figure 16.6 (see also Figure 16.7).

Physical Exclusion from Facilities and Feed

Buildings should be rodent-proofed with concrete construction plus the use of galvanized steel, brick, aluminum, and so forth. Also, a curtain wall of wire mesh might be included in the constructed wall to prevent

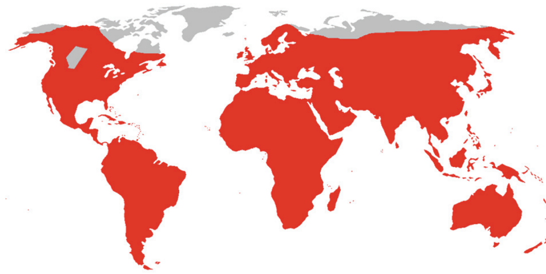
Textbox 16C

Major Rodents and their Characteristics

Brown Rat (*Rattus norvegicus*)

Brown, or Norway, rats are relatively large rodents (see Textbox 16C Figure 1). Its coat is predominantly reddish to grey-brown with the belly yellow-white with grey underfur. An adult has a head and body 7 to 10 in. (~17–25 cm) long with a tail 4.5 in. (~11 cm) long. It weighs from about 7–18 oz (~200–500 g). Brown rats are found throughout the world (except Antarctica) (see Textbox 16C Figure 2). Brown rats produce extensive systems of burrows. Tracks of rats show four toes on the front paws.

Textbox 16C Figure 1 Brown rat (*Rattus norvegicus*). (Source: Hans-JörgHellwig/Wikimedia Commons)

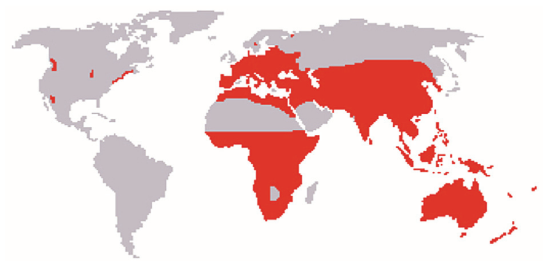


Textbox 16C Figure 2 Global distribution of brown rats (*Rattus norvegicus*). (Source: Wikimedia Commons)

Black Rat (*Rattus rattus*)

Black rats are also known as plague, ship, roof, or house rats (see Textbox 16C Figure 3). It is sleeker than the brown rat and has uniform coloration of black to gray. It has a tail that is longer than the head plus body. They weigh between 5 to 10 ounces (150 to 250 g). Black rats are found particularly in tropical and subtropical regions of the world (see Textbox 16C Figure 4). In the United States, black rats are found in the South (in the coastal states from North Carolina through to Texas, inclusive) and along the Pacific Coast. They have been out-competed by brown rats in temperate zones of the world. Black rats generally live above ground.

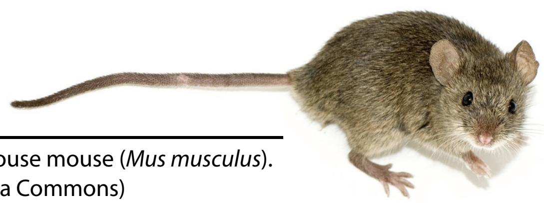
Textbox 16C Figure 3 Black rat (*Rattus rattus*). (Source: Kilessan/Wikimedia Commons)



Textbox 16C Figure 4 Global distribution of black rats. (Courtesy Wikimedia Commons)

House Mouse (*Mus musculus*)

The house mouse is gray-brown (see Textbox 16C Figure 5). An adult has a head and body about 3 in. (~8 cm) long with a tail 3 to 4 in. (~8 cm) long. It weighs about 0.5 oz (~15 g). House mice are found throughout the world (except Antarctica).



Textbox 16C Figure 5 House mouse (*Mus musculus*). (Source: Kilessan/Wikimedia Commons) rats burrowing beneath the foundation walls. Seal holes with steel wool, temporarily, followed by concrete. Rats can pass through holes with a diameter of 0.5 in. or ~1.2 cm and mice through a 0.25 in. or 0.6 cm hole. Feed should be kept in rodent-proof containers.

Trapping

Traps can be either lethal or nonlethal. Lethal traps include the conventional snap-trap (also known as spring traps or break-back traps) and the reverse-bait trigger rat trap. When using snap traps, bait with bacon or peanut butter or oats. Also, leave traps open until the bait has been taken once since rodents can be "trap shy." Nonlethal traps are referred to as humane and include trigger traps and multiple capture traps. Note that rats and mice frequently have runs along the inside or outside of walls (see Figure 16.6). This is where to trap or bait.

Smoke Bombs

Smoke or sulfur bombs are used to kill rats in underground burrows with sulfur dioxide being the toxic compound. This should only be used between flocks. There is a need for caution, following the manufacturer's instructions by workers and growers.

Rodenticides

Rodenticides are chemicals that kill rodents. They are frequently referred to as rat or mouse poison. Rodenticides are incorporated into rodent-attractive foods or baits. Baits should be placed close to burrows, feeding sites, and in paths between these. Baiting stations need to be inspected on a regular basis. Rodenticides can be categorized as (1) anticoagulants, (2) vitamin D or vitamin D-type, which cause hypercalcemia (high blood concentrations of calcium) and death within 2 days, and (3) others.

Anticoagulants

The anticoagulant rodenticides are related to coumarin or vitamin K. The first of these was warfarin. Anticoagulant rodenticides are slow-acting, requiring about 3–5 days to be effective with multiple doses needing to be consumed. They work by preventing blood clotting and thereby causing internal bleeding (e.g., around the gastrointestinal tract and in the joints). A second generation of anticoagulants has been developed that is effective even against rats and mice-resistant to first-generation anticoagulants. An example is bromodiolone. A list of anticoagulant rodenticides follows:

- Brodifacoum (Havoc®, Talon®)
- Bromodiolone (Maki®, Contrac®)
- Chlorophacinone (RoZol®)
- Difethialone (Generation®)
- Diphacinone (Ramik®)
- Pindone (Pival®)
- Warfarin (Ferret®, Contrax®)
- Other anticoagulant rodenticides include coumachlor, coumafuryl, coumatetralyl, difenacoum, and flocoumafen.

Vitamin D

Vitamin D or vitamin D metabolite-containing rodenticides include ergocalciferol and cholecalciferol

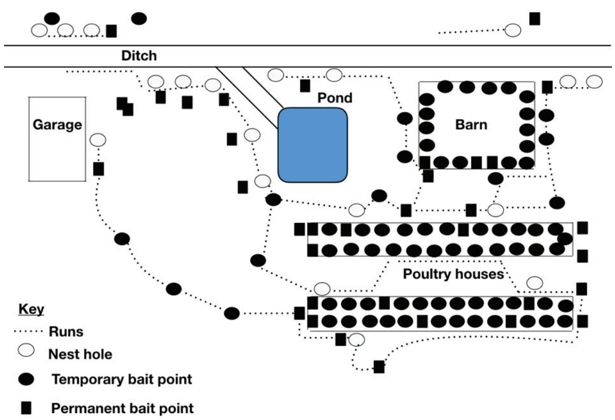


Figure 16.6 Sites for rats and rodenticide/baiting around poultry houses (modified from the Arbor Acres manual).

Figure 16.7 Rat baiting station by a turkey house. (Photo courtesy of the Iowa Turkey Federation)

Textbox 16D

How Organic Poultry Producers Can Control Rodents

Some natural products are prohibited, including arsenic and strychnine. Man-made approaches allowed include sulfur dioxide (smoke bombs), vitamin D3 as a rodenticide (but not as the sole method of rodent control), and trapping. Some people suggest that encouraging natural predators of rodents such as owls, hawks, and snakes is an effective means of rodent control.

(vitamin D_3). Commercially available rodenticides based on vitamin D include the following: Quintox, True Grit Rampage, and Ortho Rat-B-Gone.

Other Rodenticides

They include the following:

- Bromethalin (Assault®, Vengeance®)—a central nervous system toxin causing paralysis.
- Zinc phosphide (Ridall®, ZP®)—phosphide gas (smelling like garlic) is released and kills via paralysis of the heart plus damage to the liver and intestines. Phosphide is also available as aluminum and magnesium phosphides.
- Other poisons are, or have been, used—strychnine (a botanical); the inorganics such as thallium (thallium sulfate), arsenic (arsenous oxide, potassium arsenite, and sodium arsenite), sodium or potassium nitrate, yellow phosphorus, and hydrogen cyanide; the organochlorides (e.g., lindane); the organophosphorus rodenticides (e.g., phosacetim); and the unclassified rodenticides (e.g., chloralose, sodium fluoroacetate).

These can be hazardous to pets, poultry, and people. It is critical to follow the manufacturer's instructions.

16.8 Darkling Beetles

Darkling Beetle

Class: *Insecta*
Order: *Coleoptera*
Family: *Tenebrionidae*
Species: *Alphitobius diaperinus*

Darkling beetles, or litter beetles, are serious pests that infest poultry houses (see Figure 16.8A). These insects reproduce at a tremendous rate with adult beetles laying about 800 eggs in 42 days. The eggs hatch to release a larva. After pupation (2–3 weeks), the adult emerges. Darkling beetles can be at densities of over one thousand per square meter (or per square yard) (see Figure 16.8B). They consume poultry feed, carry pathogens, and cause damage. It is important to check for darkling beetles (see Figure 16.8C). Another issue is that darkling beetles can fly about 0.8 km (0.5 miles) and hence infect neighboring farms. Insecticides can be used to combat darkling beetles.

16.9 Other Pests

Other pests include feral cats, raccoons, opossums, and snakes. These may feed on mortalities around poultry houses or, if they can gain entrance to the poultry houses, can either kill the birds or cause deaths due to birds piling on each other.

16.10 Beak Conditioning

Beak conditioning is a normal practice when the chickens and turkeys are raised in confinement. This practice trims a bird's beak, removing about a third. Among the methods to accomplish beak conditioning are infrared beak trimming at a day old, and hot-blade beak trimming performed at between 1–10 days old, with parts of the upper and lower mandibles removed.

Hot-blade trimming both cuts and cauterizes using a heated (650–750°C) blade. This prevents bleeding and is effective in trimming the beak. Infrared beak trimming employs high intensity radiant heat. The advantages of infrared beak trimming are that the process is automated, there is no bleeding, and it provides consistency.

Beak conditioning reduces cannibalism and feather-picking. The procedure reduces losses from mortality from beak-inflicted open wounds, particularly from vent-cloacal injuries. After beak conditioning, poultry are less stressed and there is improved bird welfare. Beak trimming is a widely used practice in the poultry industry. Beak trimming is normally performed in a precise manner.

Most producers perform beak trimming on day-old chicks at the hatchery. They are more easily handled at this age, and hatchery beak trimming is convenient. Other producers consider that stress is minimized if beak trimming is delayed until chicks are 7 to 14 days of age. Beak trimming at the latter stage is usually more uniform and effective for a longer period.

A. Darkling beetle (*Alphitobius diaperinus*). (Source: S.E. Thorpe/Wikimedia Commons.)

B. Darkling beetles in poultry litter. (Source: Magno Borges/Wikimedia Commons.)

C. Checking for beetles in poultry litter. (Photo courtesy of the Iowa Turkey Federation)

Figure 16.8
Darkling beetle.

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17

Poultry Houses and Equipment

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List and discuss major factors in determining building placement.
2. Know the advantages of integrators providing growers with requirements for housing and equipment.
3. Know what ppm is.
4. Know the concentration of carbon dioxide in the atmosphere.
5. Know the upper limit of carbon dioxide in poultry houses.
6. Know the upper limit of ammonia in poultry houses.
7. Know how the goals for carbon dioxide and/or ammonia in poultry houses are achieved.
8. Define the following: homeothermy; thermoregulation; and thermoneutral, or comfort, zone.
9. Explain how latent heat is important for poultry and poultry houses.
10. Define sensible and insensible heat loss.
11. Define convection, radiation, and conduction.
12. Define vapor barrier and give its function.
13. List the major reasons for insulating buildings.
14. Discuss the purpose of lighting in buildings.
15. Give recommendations for lighting of different classes of poultry.
16. Discuss heat production and loss by a bird, giving reasons for its consideration in building construction.
17. Define insulation, list desirable properties, and give common examples of insulating materials.
18. Define R-value.
19. List and describe the main types of building floors.
20. Understand how poultry can be cooled in hot weather.
21. Have an overall grasp of what issues to consider when siting a poultry facility.
22. Know what the first actions are when constructing a new poultry facility.

23. Know if weather should influence the design of a poultry house.
24. Explain why poultry houses are ventilated.
25. Know why a standby generator is required.

17.1 Introduction

Well-designed housing and equipment are critical for poultry production and welfare. The junglefowl, ancestor of the domesticated chicken, lived in a limited geographical area in Southeast Asia. These birds gain protection from weather (e.g., radiant heat from the sun and the wind) by vegetation. Housing protects poultry from cold or hot ambient temperatures and from precipitation (rain, snow, hail, and sleet). High summer temperatures decrease weight gain in broiler chickens and turkeys while also depressing egg production (see Table 17.1). Both the high temperatures of summer and low temperatures of winter add costs to the grower/producer because of the utility need for misters/foggers or cooling pads in the summer (requiring electricity and water) and heaters (natural gas or propane) during the winter and for brooding. Housing also allows light intensity and day length to be varied, for instance to maximize egg production. Poultry houses and equipment make it possible to care for the flock to maximize production and assure poultry welfare using a minimum of labor.

Poultry buildings need to be adapted to diverse conditions. This is clear from a map showing US winter temperature zones (Figure 17.1), particularly related to the amount of insulation needed in poultry houses. There are multiple manufacturers and suppliers of poultry houses and equipment but, like many aspects of poultry production, there is increasing consolidation of these.

Issues for poultry houses include (1) costs for construction and maintenance; (2) stocking density (see Table 17.2); (3) temperature control (poultry well-being); (4) humidity control (poultry well-being, litter quality, and building structures); (5) insulation—poultry houses are insulated to improve air quality, for poultry welfare, and for temperature control; (6) vapor barrier—fiberglass insulation batts can incorporate a 6 mil (6 thousandth of an inch or 0.15 mm thick) poly vapor barrier; (7) ventilation—essential for poultry well-being and litter quality; and (8) lighting—day length and light intensity. High temperatures have a larger effect if accompanied by high humidity (see Table 17.1).

17.2 Overview of Buildings and Equipment

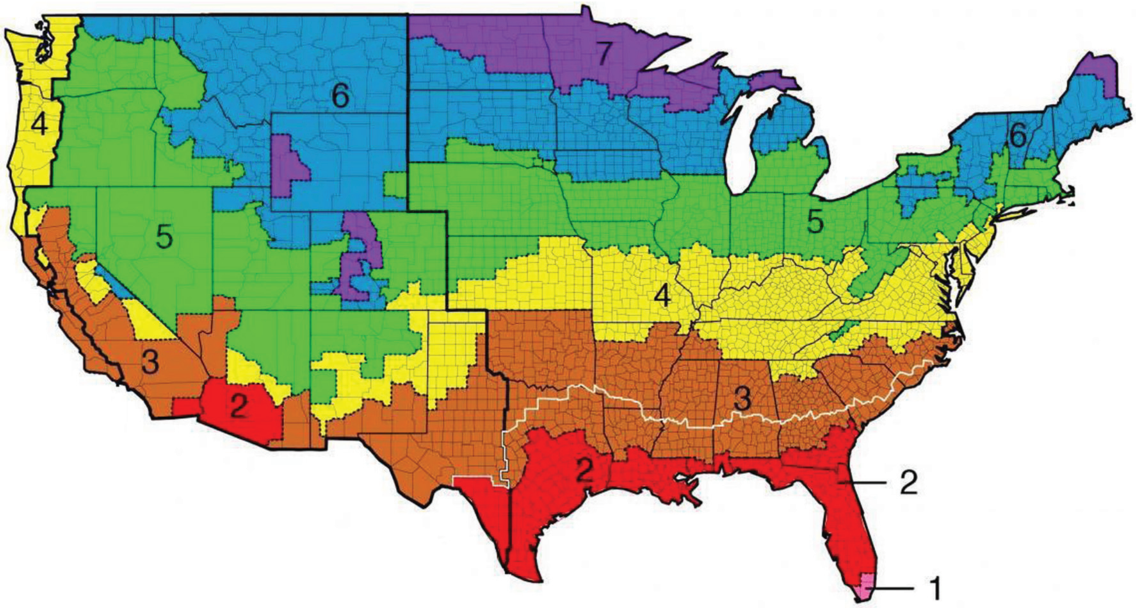
Types of Housing

Commercial housing includes tunnel housing, poultry houses with curtain windows/opening, and poultry houses equipped for layer/pullet cages. Niche

Table 17.1 Temperatures for laying hens that indicate problems of heat stress and measures to address these.

	Temperature °F (°C)				
	Humidity				
Hen Status	**10%**	**30%**	**50%**	**70%**	**90%**
Satisfactory. Bird comfort.	< 82°F (< 28°C)	< 79°F < 26°C)	< 72°F (< 22°C)	< 72°F (< 22°C)	< 68°F (< 20°C)
Alert. Increase ventilation and use foggers.	82–90°F (28–32°C)	79–86°F (26–32°C)	72–79°F (22–26°C)	72–79°F (22–26°C)	68–79°F (20–26°C)
Danger. Further increase ventilation, use evaporative cooling, flush water lines with cold water, reduce energy in diet, stop feeding at highest temperature of day, and increase nocturnal cooling.	> 90°F (> 32°C)	86–93°F (32–36°C)	79–93°F 26–34°C)	79–90°F (26–32°C)	79–86°F (26–30°C)
Emergency. Extreme danger of heat stress.	> 98.5°F (> 37°C)	> 97°F (> 36°C)	> 93°F (> 34°C)	> 90°F (> 32°C)	> 86°F (> 30°C)

Based on Iowa State Extension and Hy-Line.



All of Alaska is in Zone 7, except the following boroughs in Zone 8: Bethel, Northwest Arctic, Dellingham, Southeast Fairbanks, Fairbanks N. Star, Wade Hampton, Nome, Yukon-Koyukuk, and North Slope.
Hawaii, Guam, Puerto Rico, and Virgin Islands are in Zone 1.

Zone	Gas	Heat Pump	Fuel Oil	Electric	Attic	Cathedral Ceiling	Cavity	Insulation Sheathing	Floor
1	•	•	•	•	R30 to F49	R22 to R38	R13 to R15	None	R13
2	•	•	•		R30 to R60	R22 to R313	R13 to R15	None	R13
				•	R30 to R60	R22 to R38	R13 to R1S	None	R19–R25
3	•	•	•		R30 to R60	R22 to R38	R13 to R15	None	R25
				•	R30 to R60	R22 to R38	R13 to R15	R2.5 to R5	R25
4	•	•	•		R38 to R60	R30 to R38	R13 to R15	R2.5 to R6	R25– R30
				•	R38 to R60	R30 to R38	R13 to R15	R5 to R6	R25–R30
5	•	•	•		R38 to R60	R30 to R38	R13 to R15	R2.5 to R6	R25– R30
				•	R38 to R60	R30 to R60	R13 to R21	R5to R6	R25–R30
6	•	•	•	•	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25–R30
7	•	•	•	•	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25–R30
8	•	•	•	•	R49 to R60	R30 to R80	R13 to R21	RS to R6	R25–R30

*These recommendations represent cost-effective levels of insulation based on the best available information on local fuel and materials costs and weather conditions. Consequently, the levels may differ from current local building codes.

Source: Department of Energy, Energy.gov

Figure 17.1 Map of the United States showing climatic regions and the R-values required. (Source: US Department of Energy)

Table 17.2 Stocking densities shown in different units recommended for meat-type chickens by the National Chicken Council using different units.[1]

Parameters	Categories of Broiler Chickens			
Chicken weight (kg)	**< 2.04**	**2.04–2.55**	**2.55–3.40**	**> 3.40**
Chicken weight (lb)	< 4.5	4.5–5.5	5.5–7.5	> 7.5
Density (kg m^{-2})	**31.7**	**36.6**	**41.5**	**43.9**
Density (lb ft^{-2})	6.5	7.5	8.5	9.0
Density (# m^{-2})	**15.5**	**14.4–17.9**	**12.2–16.2**	**< 12.9**
Density (# ft^{-2})	> 1.44	1.36–1.66	1.13–1.54	< 1.20
Density (m^2 #$^{-1}$)	**0.064**	**0.055–0.069**	**0.062–0.081**	**> 0.078**
Density (ft^2 #$^{-1}$)	< 0.69	0.60–0.74	0.65–0.88	> 0.83

[1] Bold in metric units, non-bold in US customary or Imperial units.

and other housing include fixed housing, with or without access to the outdoors, and moveable housing (coops) for pasture-raised.

Planning

There needs to be sufficient space for loading, unloading, and for trucks turning, taking into account their turning circle (see Figure 17.2). Another consideration is that the efficiency of labor (grower or family or hired labor) is greater with large houses than multiple small houses.

Land Clearing

Land clearing requires the removal of tree stumps, major roots, clearing piles, and any other obstacles. The site requires a flat area that can be over 700 feet (213 m) long. Grading is performed by a grading contractor. There needs to be a compacted earthen pad for the entire building.

Figure 17.2 Poultry house on site pad showing end and side views. (Photo courtesy of Michael Czarick, University of Georgia Cooperative Extension Service)

Foundations

Considerations for a poultry house foundation are concrete footings, foundations that support the weight of the building, and foundations that match the walls of the buildings.

Dimensions

Broiler houses are between 40–60 ft (12–20 m) wide and 300–600 feet (100–200 m) long. This may be related to standard lengths of timber.

Floors, Roof, Ceilings, and Walls

Floors may be concrete, compacted soil, or slotted. The advantages of concrete are the ease of cleaning and disinfection, and the prevention of pest problems, particularly rodents. The disadvantage of concrete floors is obviously the cost. Slotted floors have slots through which excreta passes to a storage area below or nearby. Such floors have been used in Europe for over 200 years but are rarely used in the US except for broiler breeders. The advantages of slotted floors are (1) less space per bird is needed, (2) bedding is eliminated, (3) excreta handling is reduced, (4) sanitation is increased, and (5) labor savings are increased.

Roofs need to be waterproof to prevent leaks that can lead to wood rot. The roof should have a pitch of at least 4 inches per foot (ratio 1:3 in height: length; see Figures 17.2 and 17.3). Roofs can be reflective, reducing the effects of the sun heating of the building in the summer. Roofs should be lined with insulation.

Poultry houses can have dropped ceilings to improve overall ventilation and prevent the disruption of air flow through the rafters (see Figures 17.2. and 17.3). The presence of ceilings also improves heat management. The walls of many broiler houses are made of galvanized metal. Walls made of aluminum siding are used to reflect heat radiation. The walls are lined with insulation and a double aluminum wall readily allows insulation to be added.

Insulation

An insulating material is resistant to the flow of heat (to conduction). Insulation materials are commonly used in the walls and ceilings of poultry houses (dis-

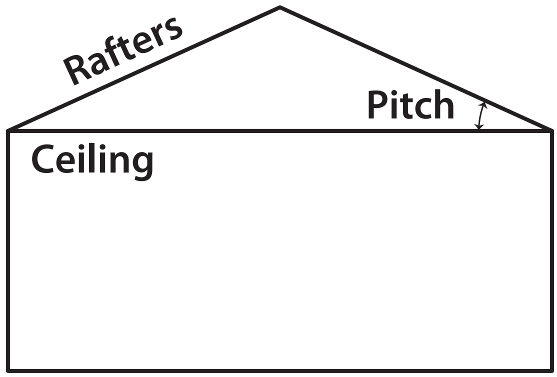


Figure 17.3 Schematic section through poultry house showing the pitch of the roof, the location of the rafters and the position of the ceiling.

cussed in more detail below). Proper insulation makes for cooler houses in the summer and warmer houses in the winter, together with substantial fuel savings.

How Heat Flows

The three mechanisms of heat flow are conduction, convection, and radiation. **Conduction** is the way heat moves through materials, such as when a spoon placed in a hot cup of coffee conducts heat through its handle to your hand. **Convection** is the way heat circulates through liquids and gases. This is why lighter, warmer air rises, and cooler, denser air sinks in your home. **Radiant heat** travels in a straight line through air and heats anything solid in its path that absorbs its energy. Insulation is resistant to conductive heat flow and is measured by its thermal resistance or R-value.

Insulation and R-values

- R-value measures thermal resistance or the resistance to the conduction of heat (for examples of R-values see Table 17.3.)
- Doubling the thickness of an insulator doubles the thermal resistance.
- R-value (R = RSI × 5.68) units in the United States are hr × ft^2 × °F/Btu (hr × ft^2 × °F × Btu^{-1}).
- R-value in the SI system (metric or Système international) is labeled RSI (RSI = R-value × 0.176).
- RSI units are m^2 × K/W (square-meter, degree kelvin, $watt^{-1}$) or m^2 × °C/W).

Table 17.3 Insulation (R-values) of various building materials and insulators.

Material	Thickness	R-value
Aluminum siding, not insulated	—	0.61
Plywood	1 inch (2.5 cm)	1.2
R-11 mineral fiber	16 inches (41 cm)	5.5
Loose or blown cellulose	1 inch (2.5 cm)	3.5
Expanded extruded polystyrene	1 inch (2.5 cm)	5.0
Polyurethane foam	1 inch (2.5 cm)	6.25
Polyisocyanurate (foil faced)	1 inch (2.5 cm)	7.2

Building Integrity

It is important to have tight houses with well-fitting doors and the absence of holes and cracks. Without this, there is leakage of air, reduced effectiveness of ventilation, and risks of rodents, insects, and wild birds getting into poultry houses with consequent risk of diseases.

Impact of Weather

Rain, snow, or wind can affect poultry houses. Windrows of trees and bushes can be helpful in reducing the effects of wind (see Figure 17.4). Build-up of snow or ice on the roof can lead to disastrous building failure. This can be alleviated by the roof having a pitch of at least 4 inches per foot (ratio 1:3 in height: length) (see Figure 17.2). The gable roof should be water tight. EF3 (Enhanced Fujita scale) or greater tornadoes with wind speeds of more than 135 mph (217 kmph) results in severe damage to even well-constructed poultry buildings. Moreover, poultry houses are susceptible to damage from hurricanes and other major wind events.

Storm Water Drainage

Where possible, the soil should be porous and the slope gentle, which contributes to dryness. Construction should not be close to waterways or wetlands. However, wetland or restored wetlands can be used successfully to reduce the impact of poultry operations on waterways (see Figure 17.5). Depending on geographic

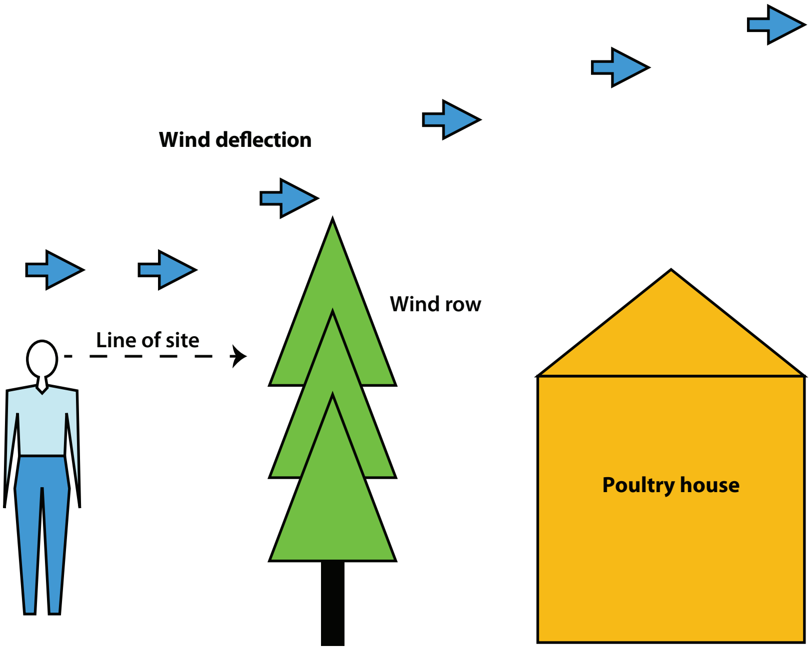


Figure 17.4 Windrows of trees and bushes are valuable for improving the views of neighbors and reducing the impact of odors.

A. Restored wetland in California. (Source: USDA NRCS/Gary Kramer)

B. Restored wetland in Arkansas. (Source: USDA NRCS/Robert G. Price)

Figure 17.5 Wetlands provide a mechanism to remove runoff from poultry houses or animal waste and hence protect waterways.

area, storm-water runoff can be diverted into retention ponds, via drainage ditches, and splash grass swales. There should be a grass buffer.

17.3 Locations for Buildings

Poultry buildings should be located to ensure an efficient and profitable operation, and to address biosecurity while being pleasant for operators and neighbors.

Issues

1. **Water supply.** High-quality water (well or surface water or main/city) must be available and plentiful. Low-quality water adversely impacts production.
2. **Roads.** It is preferable that poultry buildings be located near an all-weather road or highway (but preferably not used for transportation of other poultry).
3. **Telephone and electricity.** The units should be near electric lines and have access to landline telephone and/or reliable cell phone coverage.
4. **Topography.** The topography should be high and level with no abrupt slopes. A relatively level area requires less site preparation and, thereby, lowers building costs.
5. **Water Drainage.** This needs to be considered when locating building. Irrespective of region, it is essential that proper drainage prevent standing water adjacent to the poultry houses.
6. **Access to labor** (i.e., ability to hire suitable employees).
7. **Layout of operations** to allow ease of the delivery of chicks/poults, feed, and litter; the removal of spent litter, and the marketing of birds.
8. **Landscaping** (trees, and so on). Landscaping is a valuable attribute. Trees and bushes provide privacy from neighbors, disrupt wind patterns, disperse odors and reduce local temperatures. A regularly cut grassy area aids rodent detection and makes the facility look well cared for.
9. **Fire protection.** Poultry buildings should be far enough apart so that fire will not spread easily from one building to another. In general, this means at least 100 ft (30 m) apart in the case of large buildings.
10. **Appearance.** Careful attention to the arrangement of buildings adds to the attractiveness of the unit. Unsightly objects (e.g., lagoons, etc.) should not be visible from the highway. Fences and buildings should be repaired and painted regularly; and yards and driveways should be kept free of trash or rusty equipment.
11. **Expansion.** Provision should be made for easy expansion. It may be possible to expand buildings by extending their length. It is important that other buildings or utilities do not interfere.

17.4 Building and Equipment for Contract Growers

The integrator will provide the grower with lists of requirements for houses and equipment (including manufacturers and suppliers) including house type and dimensions, controllers, fans, feeders, and waterers. There may be options from two or three equipment suppliers. The grower works with the building coordinator (an employee of the integrator) on building specs, the construction company (or companies), and equipment companies. The advantages for this include a common system that can be evaluated, standardization, economies of scale for manufacturers and suppliers, and the potential for discounts.

17.5 Principles of Temperature Control

Poultry are warm-blooded (homeothermic), maintaining their body temperature within a very narrow range. At environmental temperatures below the thermoneutral zone, metabolic heat needs to be generated to maintain core body temperatures. At environmental temperatures above the thermoneutral zone, metabolism needs to dissipate heat and maintain core body temperatures (see Figure 17.6).

In the thermoneutral zone: Metabolic heat → Environment (conduction, convention, and radiation); Metabolic heat gain by bird = Environment heat loss (conduction, convention, and radiation). The optimum temperature or thermoneutral zone for chickens is 68–75°F (20–24°C) for layers and 70–75°F (21–24°C) for broilers. The core body temperature for chicken is 104–107.5°F (40–42°C).

Definitions

Homeothermy (noun) or **homeothermic** (adjective): Birds and mammals are homeotherms, or warm-blooded. They maintain their core temperatures within very close limits.

Thermoregulate (verb) or **thermoregulation** (noun): This is the ability to maintain core body temperatures.

Thermoneutral zone: This is the ambient temperature(s) where an animal can maintain its core body temperature without needing to take efforts to either raise or lower its temperature. This **thermal comfort zone** is the temperature where metabolic energy does not need to be used to maintain the core body temperature (see Figure 17.6). Biologically, it is the most efficient temperature for production, with the best feed conversion rates.

Dry bulb temperature: This is the actual or real temperature.

Wet bulb temperature: This is the temperature that would need to be lowered to achieve 100% relative humidity. At 100% humidity, the wet bulb temperature is equal to the dry bulb temperature. At lower humidity, the wet bulb temperature is lower than the dry bulb temperature.

Heat Stress index (in degrees Fahrenheit): Heat Stress index = 0.6 × temperature in ºF from dry bulb thermometer + 0.4 × temperature in ºF from wet bulb thermometer. Heat stress index should be less than 70 using degrees Fahrenheit.

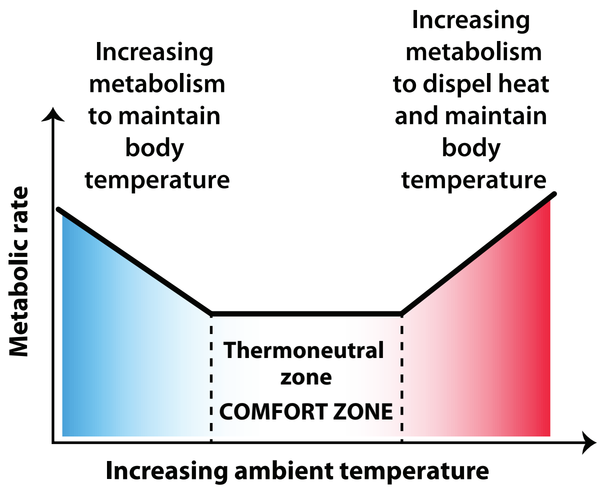


Figure 17.6 The concept of the thermoneutral or comfort zone. At temperatures below or above the thermoneutral zone the animal has to exert energy to maintain its temperature at the set point.

Heat Production by Poultry

Chickens and other poultry lose heat through both sensible heat loss and insensible (latent heat) heat loss. The ability of young birds (chicks and poults) to thermoregulate and hence achieve a consistent body temperature is not fully developed until about 12 days old.

Sensible Heat Loss

As mentioned above, heat is lost to the environment through, conduction, convection, or radiation. For a chicken, heat is lost by conduction from the feet to the litter, particularly when the litter is wet. Heat is lost by radiation and convection from the chicken's body and head, particularly from regions not covered by feathers and those surfaces with high blood flow. The results of poultry losing heat are increases in the temperature of the air in a poultry house together with the litter. With increased air flow (ventilation), there is more sensible heat loss.

Insensible Heat Loss or Latent Heat (of Vaporization) (L_v)

Latent heat is energy from when there is a change in phase, e.g., cooling from when liquid water changes to water vapor (e.g., in the lungs decreasing the temperature of poultry or misting to reduce temperatures in a poultry house).

$$\text{Latent heat } (L_v) = \frac{\text{Energy or heat absorbed or released with phase change (liquid to vapor)}}{\text{Mass}}$$

The heat of vaporization of water is 2,260 kJ kg^{-1} or 540 Calories (kilocalories) kg^{-1}. This is the heat required to boil water or the heat absorbed when water evaporates in the lungs and respiratory ducts of the bird.

Definitions

Calorie: A unit of heat or energy. One calorie is the amount of heat required to raise the temperature of one gram of water by one degree Celsius.

Joule: A unit of energy or work done. One calorie equals 4.2 joules (J). One kilocalorie equals 4.2 kilojoules (kJ). One thousand kilocalories (kcal or Cal) equals 4.2 megajoules (MJ). Moreover, 3600 joules equal to one watt-hour.

Latent heat: Also known as the heat of vaporization of water, it is 2,260 kJ kg^{-1} (kJ per kg) or 540 Calories (kilocalories) kg^{-1}. This is the heat required to boil water or the heat absorbed when water from misters or foggers or cooling pads evaporates.

17.6 Cooling Poultry Houses

Poultry welfare and efficient production requires cooling poultry houses. Cool cell pads or evaporative cooling pads are used extensively in broiler houses (see Section 17.9). Misters/foggers are still used in turkey

TEXTBOX 17A

A Deeper Dive: Latent Heat Loss from Poultry

As environmental temperatures rise, there are dramatic increases in the loss of heat from laying hens; latent heat loss in laying hens being 5.1 W m^{-2} (0°C), 21.5 W m^{-2} (25°C), 43.4 W m^{-2} (38°C) (Richards, 1977). Age-related changes in sensible and insensible heat production are summarized in Textbox 17A Table 1.

Textbox 17A Table 1 Age-related changes in heat production in broiler chickens.

	Heat Production in W kg^{-1}		
Age (Weeks)	Sensible Heat Production (SHP)	Insensible Heat Production or Latent Heat Production (LHP)	Total Heat Production (THP)
1–2	14	4	18
2–3	7	6	13
4–5	5	4	9

Calculated from Chepete and Xin, 2001.

houses and are also used as a reserve or supplementary system for broilers. These systems employ the principle of latent heat of vaporization of water. In addition, ventilation with high wind speeds reduces the temperature that birds are experiencing by a wind chill effect (discussed in Section 17.9). Note that with increases in temperature there are large increases in the amount of water in the atmosphere (see Table 17.4).

Cool Cell Pads

Cool cell pads or evaporative cooling pads are effective in reducing the temperature in poultry houses (see Section 17.5). Pads look like paper air filters. They are wetted by either fogging nozzles or water dripping on to them. They are placed at the air inlet so that air entering the house is cooled by evaporation. Evaporative cooling pads have largely replaced foggers/misters as the major mechanism for cooling in broiler houses in the United States. However, there can be problems with the build-up of algae.

Misters/Foggers

Misters or foggers are used to reduce the temperature in poultry houses. Again, these employ the principle that evaporation of water requires absorption of energy or heat. Misters or foggers are used to supplement cool cell pads. The relationship between water pressure and droplet size is summarized in Table 17.5. With increasing pressure, droplets are smaller and more rapidly vaporize decreasing atmospheric temperature.

Table 17.4 Effects of temperature on the maximum water vapor (saturation) in air.

		Maximal Water Vapor	
Temperature °C	Temperature °F	g m^{-3}	lb per 1000 square feet
-20	-4	1.05	0.066
0	32	4.89	0.31
10	50	9.39	0.59
20	68	17.3	1.07
30	86	30.4	1.9
40	104	51.1	3.2
50	122	83.0	8.1

Table 17.5 Effect of water pressure on water droplet size.

	Water pressure		
Pressure	kPa kilopascal*	PSI—lb force per square inch	Droplet size Microns (μ)
Low	689–1379	100–200	< 30
High	2758–4137	400–600	10–15
Ultra-high	4826–6890	700–1000	5

* One pascal (Pa) is the force of one newton per square meter. One kilopascal (kPa) = 1000 Pa.

17.7 Heating Poultry Houses

The presence of birds in a poultry house increases the temperature, the heat being dissipated into the environment. Heat is lost from the house via ventilation. In cold weather, poultry houses need to be heated. Systems to heat a poultry house include the use of propane or oil, such as the following:

- Forced-air space heaters (rated between 80,000 to 250,000 BTUh) with four such heaters being required for a 500 ft (152 m) long house.
- Radiant tube heaters. Infrared radiation emitted from the brooder increases the temperature of the litter. This improves bird comfort.

Table 17.6 illustrates the costs of heating poultry houses with oil or propane.

The heating requirement for an older house is 630,000 BTU per hour. For a new house the heating requirement is 302,000 BTU per hour (forced air) or 286,000 BTU per hour (radiant tube) (data from Donald and Czarick, 2003).

Table 17.6 Comparison of propane and oil for heating poultry houses.

	BTU per Gallon (Megajoule per Liter)	Cost US$ per Gallon
Propane	90,000 (25)	0.90
# 5 Oil (Filter Motor Oil)	140,000 (39)	0.50

Based on Simpson et al., 2016.

17.8 Air Quality in Poultry Houses

Obviously, poultry houses contain the same gases as in the atmosphere; namely (with concentrations shown as in the atmosphere): nitrogen (78.1%), oxygen (20.9%), argon (0.9%), and carbon dioxide (0.04%). The concentration of carbon dioxide can also be expressed as parts per thousand (ppt) and parts per million (ppm), namely ppm 0.4 ppt or 400 ppm.

What Is ppm?

ppm = parts per million
The corollaries are the following:
ppt = parts per thousand
ppb = parts per billion
% = parts per hundred

The atmosphere inside a poultry house **is not** the same as the atmosphere for several reasons:

- The birds are breathing in air, taking out oxygen.
- The birds are breathing out air, with less oxygen but much more carbon dioxide and water vapor.
- Natural gas or propane heaters use oxygen and emit carbon dioxide, potentially with some carbon monoxide.
- The litter is receiving the bird's excreta, both urine (high in uric acid) and feces. There is microbial fermentation generating emissions of predominantly carbon dioxide and ammonia (together with some nitrous oxide).
- Where evaporative cooling is used, this will lead to increased humidity (see Figure 17.7).

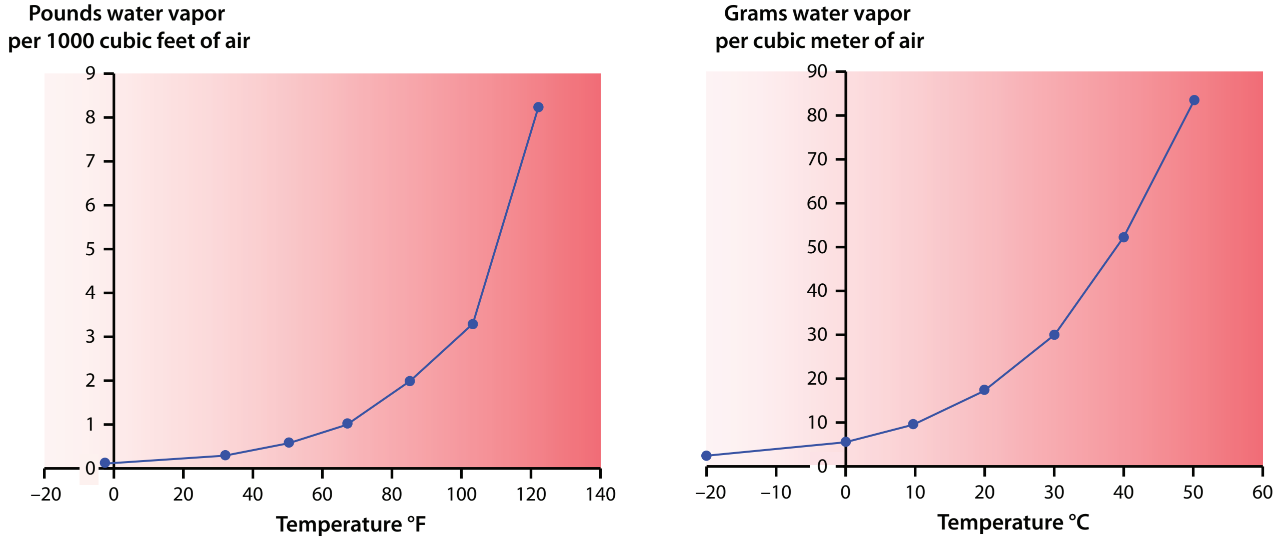
It is important to ensure the air quality of poultry houses within the following parameters:

- Ammonia (NH_3) ideally below 10 ppm.
- Carbon dioxide below 3000 ppm (at 3500 ppm, there is a risk of ascites).
- Carbon monoxide below 10 ppm (at 50 ppm, bird health is adversely affected and higher concentrations can lead to mortalities and problems for the workers).
- Water vapor—the humidity should be between 50 and 60% after brooding. A 2.3 kg broiler chicken will add about 4.9 liters (1.3 gallons) of water predominantly to the atmosphere of the poultry house with some going to the litter.
- Dust levels should be very low otherwise there will be damage to the respiratory tract lining and hence increase the risk of disease.

It is essential that ventilation brings the concentrations of noxious gases down to acceptable levels, such as less than 10 ppm for ammonia, less 3000 ppm for carbon dioxide, and less than 10 ppm for carbon monoxide. Higher levels of these gases can impact the performance of the poultry (decreased growth and feed efficiency together with increased mortality) and the health of the workers in the facility.

Immediately after entering a poultry house, the caretaker should ask: Does it feel stuffy or humid? Is the air quality acceptable? Is there an odor of ammonia? It is possible to use instruments to determine relative humidity together with carbon dioxide, carbon monoxide, and ammonia concentrations in poultry houses. These facilitate decision-making on ventilation and assure the welfare of the birds and workers.

The most common noxious gas in poultry houses is ammonia (NH_3). This is mainly generated from the decomposition of excreta. Elevated concentrations of ammonia in broiler chicken houses impacts bird well-being, reducing production efficiency. In addition, this can compromise the health of workers. Ammonia from poultry houses (and other livestock) is usually naturally deposited/precipitated within 24 hours within 1 km (5/8 mile) and hence into the watersheds, although the amount of wind will impact this. Alternatively, the ammonia can combine with acids to form aerosols and these stay in the atmosphere for about 15 days.



A. Temperature in °F and amount of water vapor in pounds per 1000 cubic feet of air.

B. Temperature in °C and amount of water vapor in grams per cubic meter of air.

Figure 17.7 The effect of increasing environment temperature on the maximal amount of water vapor.

TEXTBOX 17B

A Deeper Dive: Ammonia Release from Poultry Production

Emission is the rate of release of a gas or particulate into the atmosphere. The emission rates for ammonia (Casey et al., 2006):

- Layers: 116 g NH_3 per AU (AU or animal unit or 500 kg).
- Broilers: 135 g NH_3 per AU (AU or animal unit or 500 kg).

Emission rates in different reports vary from less than 10 to greater than 300 g NH_3 per AU suggesting either tremendous variation or that a combined with methodological problems. The US Environmental Protection Agency (EPA) estimates that emissions of ammonia from poultry account for 13.4% of the total US emissions (compared to 24.4% of the total US emissions for cattle).

The US National Institute for Occupational Safety and Health (NIOSH) has established exposure limits for ammonia for workers. These are: 25 ppm for an 8 hour workday, 35 ppm for exposure of 15 minutes, and 50 ppm for exposure of 5 minutes. Hydrogen sulfide (H_2S) is another noxious gas that can be associated with poultry and livestock (particularly pigs) production, manure, and processing. This is particularly problematic for workers and neighbors of poultry and livestock operations. In the United States, federal agencies have established ceiling levels:

- The US Occupational Safety and Health Administration places the ceiling limit for H_2S in the workplace at 20 ppm for exposure limits of 15 minutes.
- The National Institute for Occupational Safety and Health (NIOSH) consider the limit as 10 ppm for 10 minutes exposure with 100 ppm as "immediately dangerous to life or health."

Research indicates that the ideal conditions for raising poultry have concentrations of ammonia in the air of less than 10 ppm. However, the poultry industry standard is that ammonia concentrations are less than 25 ppm. It is important to have satisfactory levels of ventilation to reduce atmospheric ammonia concentrations in poultry houses below the threshold concentrations.

17.9 Ventilation

Ventilation (air movement) is required for air quality in the poultry house (removing, for instance, ammonia, carbon dioxide and dust); moisture in the house and, hence, litter quality (removing water vapor); and bird comfort, with there being a breeze or wind chill from the air movement. Without adequate ventilation, feed consumption and, hence, growth will be depressed. Wind chill at 300 ft per min (1.5 m per sec) wind chill = 4°F (2.2°C), 450 ft per min (2.3 m per sec) wind chill = 8.5°F (6.7°C), and 600 ft per min (3.0 m per sec) wind chill = 15°F (8.3°C).

Ventilation is controlled by the use of fans (including multispeed fans) operated both continuously and controlled by thermostats. Ventilation systems may be classified as either of two types: negative pressure or positive pressure. In the negative pressure system, exhaust fans expel air that has been drawn into the pen through intakes, usually located in the opposite wall (see Figure 17.8). The positive pressure system uses fans to force air into the pen and air escapes out through ventilation openings. The former system makes it easy to filter and/or cool the incoming air. It is important that fans be regularly cleaned, inspected and, where necessary, worn parts are replaced. During brooding during the first week of life, excessive ventilation should be avoided.

$$\text{Fan capacity required in cubic feet per minute} = \frac{\text{length} \times \text{width} \times \text{average height}}{\text{air exchange time (1 minute)}}$$

$$\text{Air velocity} = \frac{\text{total fan capacity}}{\text{width} \times \text{average height}}$$

Water and Ventilation

The water in a carcass can be accounted by metabolic water. Thus, the consumed water, together with any spillage (6.6 liters per bird between day old and 50 days old), is added to the poultry house as water vapor in the expired air and water in the excreta (feces and urine), and hence in the litter. Water input includes water intake and metabolic water. Water output includes expired air water (water vapor), fecal water, urine water, and increase in tissue water.

Figure 17.8 Inside view of a tunnel broiler house. (Photo courtesy of Michael Czarick, University of Georgia Cooperative Extension Service)

Water Consumption

- About 6–7 liters of water is removed from drinkers per bird during the period of growth of broiler chickens to 49 days. This reflects consumption and some spillage.
- The average feed to water intake ratio of broiler chickens is 1:1.77 (between 1:1.6–1:2.0).
- Water consumption increases with age during growth of broiler chickens and turkeys.
- There is greater consumption with higher environmental temperatures.

Ventilation

For a poultry house containing 20,000 chickens, the amount of water release into the atmosphere is equal to 6.6 liters of water produced per broiler chicken though its life, which is 132,000 liters (34,871 gallons) of water produced per flock (20,000 chickens). This water is predominantly voided from the house by ventilation; however some accumulates in the litter.

Tunnel Ventilation

The fans are effective in producing high ventilation rates in the tunnel house, with moderate wind speeds inside and negative pressure outside relative to the inside (see Figures 17.9 to 17.11). Air is drawn into the house through inlets and passes over the birds and litter, removing heat (sensible heat from the birds), carbon dioxide, ammonia, water vapor/humidity, and dust. As temperatures rise, the ventilation rate needs to be increased. Moreover, the ventilation rate is reduced at night when environmental temperatures decline. Table 17.7 lists some examples of ventilation rates. More recently, 600 feet per minute (fpm) has been used and is important for broilers over 5.5 lbs (2.5 kg). Wind speed of 700 fpm can be used with high humidity and/or temperatures.

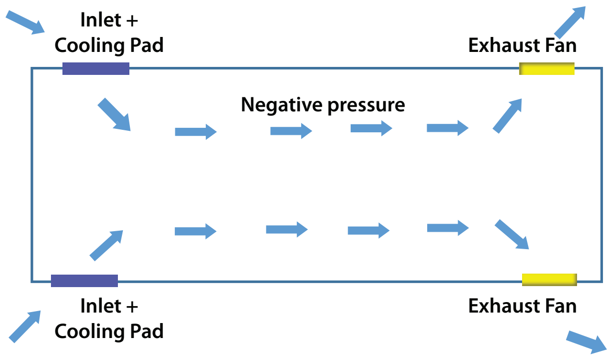


Figure 17.9 Schematic top view of a tunnel broiler house showing tunnel ventilation. There is a wind current in the house due to the exhaust fans at the end of the house moving air out and air entering via the inlets at the other end of the house due to the negative pressure. Cool pads are placed at the inlets which cool the air entering the house.

Figure 17.10 Exhaust fans moving air through a tunnel house. (Photo courtesy of Michael Czarick, University of Georgia Cooperative Extension Service)

Examples of fan output are 33,980 m^3 h^{-1} (20,000 cubic feet per minute, or cfm), or a fan efficiency rating of 28.8 m^3 h^{-1} W^{-1} (17 cfm $watt^{-1}$ [W]). As air passes through the house, the velocity declines somewhat. It is important that the broiler house be air-tight otherwise the ventilation will be less effective.

Side Ventilation

Moderate levels of ventilation of poultry houses is accomplished using exhaust fans on one side of each house. These are frequently used to provide good ventilation when tunnel ventilation exhaust fans are off, for instance, at moderate environmental temperatures (see Figures 17.12 and 17.13).

Mixing Fans

Low levels of ventilation of poultry houses can be achieved using mixing fans in the top of poultry

Table 17.7 Conversion of units of ventilation or wind speed.

	Wind Speed		
Feet per Minute or fpm	300	600	700
Meters per Minute or m min^{-1}	91	183	213
Meters per Second or m sec^{-1} or m/s	1.5	3.0	3.6
Miles per Hour or mph	3.4	6.8	8.0
Kilometers per Hour or km h^{-1}	5.5	11.0	12.9

Figure 17.11 Cooling pads at air inlets in a tunnel house. The cooling pads reduce air temperatures experienced by the birds. (Photo courtesy of Michael Czarick, University of Georgia Cooperative Extension Service)

Textbox 17C

A Deeper Dive: The Impact of Ventilation on Growth and Welfare of Broiler Chickens

At very high environmental temperatures (95°F/35°C), ventilation with a high air speed velocity results in increased growth, increased food intake, and lower body temperatures (see Textbox 17C Table 1). The reduction in body temperature is due at least in part by a large increase in heat loss by convection (see Textbox 17C Table 1).

Textbox 17C Table 1 Effects of ventilation on broiler chickens at high environmental temperatures (95°F/35°C).

Air Speed/Velocity (m per sec)	Body Weight (kg)	Feed Intake (kg)	Body Temperature °F (°C)	Heat Loss by Radiation (Kcal per d)	Heat Loss by Convention (Kcal per d)
0.8	1.88^{a}	1.19^{a}	$111.0 (43.9)^{a}$	21.7	47.9^{a}
1.5	2.07^{b}	1.49^{b}	$109.2 (42.9)^{c}$	21.9	67.3^{b}
2	2.31^{c}	1.71^{c}	$109.0 (42.8)^{c}$	27.4	90.2^{c}
3	2.16^{bc}	1.65^{bc}	$109.8 (43.2)^{b}$	27.2	114.2^{d}

$^{a, b, c, d}$ Different superscripts indicate difference.

Based on Yahav et al., 2004.

In a production setting, ventilation with high air velocity has been shown to improve bird welfare as evidenced by reduced mortality. Ventilation also improves bird performance (see Textbox 17C Table 2). There are increases in gain and improvements in feed efficiency with high ventilation during the day and lower ventilation at night. High rates of ventilation during the day and night results in further improvements in gain and feed efficiency.

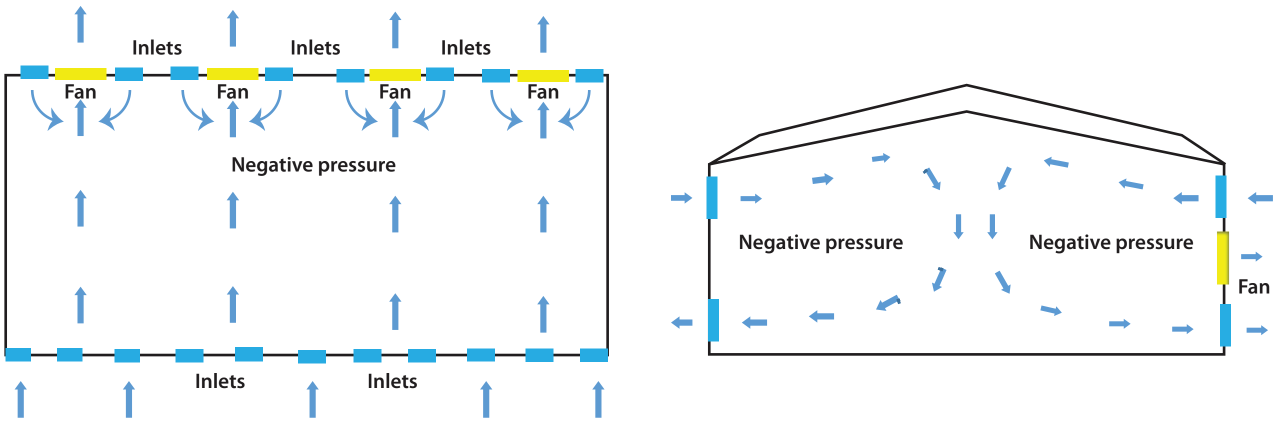
Textbox 17C Table 2 Comparison of the effects of ventilation on performance of older broiler chickens.

Parameter	Still Air	Higher Ventilation during the Day and Reduced at Night	Ventilation
Air speed	0	**Day**: 2.78 m/s (556 ft per min) **Night**: 1.67 m/s (334 ft per min)	2.78 m/s (556 fpm)
Performance days 37–51			
Gain in g	965^{a}	1166^{b}	1278^{c}
Feed consumed g	2333^{a}	2687^{b}	2764^{b}
F:G	2.42^{a}	2.31^{b}	2.16^{c}
Mortality %	8.2	4.9	4.8
Economics assuming 20,000 bird house			
Increased revenue	0	US$442	US$642
Increased costs	0	US$321	US$392
Net increase	0	US$121	US$250

$^{a, b, c}$ Different superscript letter indicates difference $p < 0.05$.

Dozier et al., 2006.

Figure 17.12 Large and smaller exhaust fans, respectively, moving air through a tunnel ventilation and side ventilation. (Photo courtesy of Michael Czarick, University of Georgia Cooperative Extension Service)



A. Top view.

B. Side view.

Figure 17.13 Schematic of a tunnel broiler house showing side ventilation. There is a wind current in the house due to the exhaust fans on one side of the house moving air out the house and air entering via the inlets on both sides of the house.

houses. These are frequently used to provide sufficient ventilation when all exhaust fans are off, for instance, at low environmental temperatures (see Figure 17.14).

17.10 Brooding for Chicks and Poults

Effective brooding is pivotal to the success of poultry production. This is discussed in Chapter 16 (brooding), Chapter 18 (laying chicken including pullets), Chapter 19 (broiler chickens), and Chapter 20 (turkeys).

Heaters are necessary for brooding, which requires heating to higher temperatures. There are two major types of heaters:

- Hanging conventional pancake brooder or area heaters (hover brooders). The use of these can result in marked temperature differences between 150°F and 75°F (62°C and 24°C) at bird level. However, more even temperatures can be achieved when these brooders are coupled with suitable fans (recirculating or paddle ceiling fans).
- Infrared or radiant brooders: Infrared radiation emitted from the brooder increases the temperature of the litter. This improves bird comfort and is, particularly, useful with turkey poults.

17.11 Feeders

Feeders should be accessible and meet the needs of all the birds while having minimal spillage. Feeders are also discussed in Chapters 18–20.

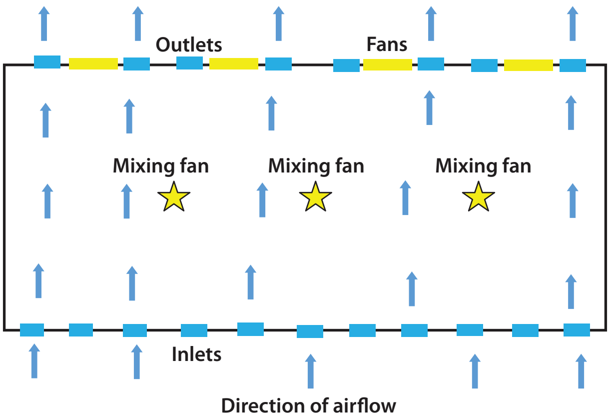


Figure 17.14 Schematic showing mixing fans in a poultry house. This provides sufficient ventilation at low environmental temperatures.

Automatic Feeder Pans

These can meet the needs of 50–70 birds per 33 cm (12 in.) diameter pan (see Figure 17.15).

Number of Lines

The number of feed lines depends of the width of the house. The following are recommendations from the Cobb Broiler Management Guide:

- 2 lines for a house width < 12.9 m (< 42 ft.)
- 3 lines for a house width 13–15 m (43–50 ft.)
- 4 lines for a house width 16–20 m (51–65 ft.)
- 5 lines house width 21–25 m (70–85 ft.)

Figure 17.15 Broiler chickens by a line of feeders and drinkers. (Source: Oleg/Shutterstock)

Automated Chain Feeders

These should provide at least 2.5 cm (1 in.) feeder space per bird. The amount of feed in the feeders is controlled by feed slides in the hoppers.

Height

Height should be such that all birds can feed and there is minimal spillage. When feeders are too high, birds will tip pans and spill the feed.

Feed Storage Bins

There should be two bins per house (see Figure 17.16). Feed storage bins should be large enough to meet the needs of the birds for 5 days. These bulk storage bins should be water-tight to reduce mold growth.

Figure 17.16 Curtain poultry house showing augering of feed to the poultry. (Source: USDA NRCS)

17.12 Lighting

Photoperiodic schedules and light intensity are covered in Chapters 18–20.

Shift from Incandescent Lights to Light-Emitting Diodes

Incandescent bulbs consume between 30–40% of the electrical utilities of a broiler flock. The shift to light-emitting diodes (LEDs) reduces energy consumption by 80–85% compared to incandescent bulbs.

17.13 Water Quality

Definitions

ppm: The units of contaminants in water are shown as mg (10^{-3} g) per liter or ppm (parts per million).

CFU: The units of bacterial contamination of water are shown as colony forming units (CFU) per ml.

Maximal acceptable levels: For drinking water, 1×10^3 CFU (bacteria number) per ml. The maximal acceptable level of fecal coliforms is 0 CFU per ml (Leakage from septic system).

Water Quality and Equipment

Water quality is important to the production of poultry, particularly for turkeys. Extra care is necessary when well or surface waters are used, but not normally with city water. Water quality can be particularly a problem if there is seepage from septic tanks or a mixing of sewage or animal waste after flooding/major rain events. Water issues include the following:

- Microorganisms (bacteria, fungi, and viruses) that can potentially multiply in the water lines before being consumed by the poultry. The presence of microorganisms can reduce water consumption and thereby suppress performance. Levels of microorganisms reported in one study had a range of 0 to 2.7×10^4 CFU (bacteria number) per ml at the source and a range of 2.7×10^5 to 4.8×10^6 CFU per ml at the end of water line (Watkins, 2008).
- pH has an acceptable range of 5–8.
- Minerals include calcium and iron.

Water Treatment

Water will be filtered, sanitized, and, depending on the hardness of the water, softened. Water needs to be tested for contaminants. **Water filtration** removes particulates and microorganisms, however as some microorganism get through and then multiply, water treatment with oxidizers or sanitizers is advisable. Oxidizers are disinfectants that kill microorganisms including pathogens. Water should be filtered before sanitizing. Sanitizers in water are effective at the following levels:

- Free chlorine 2–4 ppm at pH 5–7.
- Chlorine dioxide 0.8 ppm.
- Hydrogen peroxide 25–50 ppm (after ozone treatment).

ORP (oxidation reduction potential) is a measure of the oxidation potential of water. It reflects chlorine, chlorine dioxide, hydrogen peroxide, and other oxidizing agents, lowering the concentration of reducing agents such as microorganisms, organic matter, and ferrous iron. A high ORP of 650 millivolts (mV) or greater indicates good quality water, while a low ORP of 250 millivolts (mV) or less indicates poor quality water with the water containing organic matter, microorganisms, ferrous iron (Fe^{++}), manganese (Mn^{++}), bisulfite (HS^-), and sulfite. It can be important to use ORP meters to determine whether water is of the quality required.

Water softening has the goal of removing calcium and magnesium from water. In addition, water softening reduces manganese and soluble iron in the water. Water softening is useful if the water is hard, containing high levels of calcium (> 110 mg calcium per liter) and/or magnesium (> 125 mg calcium per li-

Textbox 17D

A Deeper Dive: Effect of Water Quality

Quality of water has been demonstrated to influence poultry production, with egg production lower when well water is used versus city/main water (Koelkebeck et al., 1999) (see Textbox 17D Table 1). Issues with well water can include elevated levels of sodium and chloride together with other ions. This data strongly suggests that producers/growers should test well water on a regular basis and consider utilizing processes to remove ions and other contaminants.

Textbox 17D Table 1 Effect of water source on laying hens.

Parameter	Well Water	City/Main Water
pH	7.8	8.4
Chloride ppm	210	80
Sodium ppm	190	29
Egg production % per day	75.3[p]	82.3[q]
Water consumption ml per hen per day	187[a]	211[b]

[p, q] Different $p = 0.06$.
[a, b] Different $p < 0.05$.

Data from Koelkebeck et al., 1999.

ter). Water softening prevents the build-up of deposits such as calcium carbonate in water lines and waterers. Water is passed through a zeolite resin and should be filtered before softening.

17.14 Drinkers/Waterers

In general, there are two major types of waterers: open systems and closed systems. Waterers are also discussed in Chapters 18–20.

Bell or Cup Drinkers (Open Systems)

Issues with open drinker systems include (1) spilled water leading to damp litter and consequently reduced quality of the litter, (2) condemnations, and (3) water hygiene becoming impaired following contamination with litter or feed.

Height

Drinkers should be suspended at a height that allows all birds access to the water (see Figure 17.15). The height should have the lip of the drinker at the same level as the top of the back of the birds standing normally. The height should be adjusted as the animals grow. Bell drinkers should have a specific length (e.g., 0.6 cm or 0.24 inch per bird) and ballast to improve stability.

Closed Systems (Nipple Drinkers)

Closed systems require water to be pressurized using either a header tank or pump system. These can be either **high-flow nipple drinkers**, with cups to collect spilled water, which are capable of delivering 80–90 ml/min (2.7 to 3 fl. oz/min) and supply the needs of 12 birds per nipple, or **low-flow nipple drinkers**, not requiring cups to collect spilled water, which are capable of delivering 50–60 ml/min (1.7 to 2 fl. oz/ min) and supply the needs of 10 birds per nipple. Waterers need to be within 3 meters (10 ft) from every bird. The nipples should be at the height of the birds' heads.

Water Meter

Water systems require a water meter. There should be a bypass such that water used to flush the system is not included in the measured amount. It is important to ensure water usage is meeting the needs of the poultry but is not excessive. Insufficient water will slow growth, while excess water consumption reflects spillage or increased consumption with increased temperatures.

TEXTBOX 17E

A Deeper Dive: Drinking and Laying Hens

When Is Water Consumed?

Water is only consumed during the day (lights on or daylight permitted) with none during the night (lights off or when the binds are down) (Xin et al., 2002). Similarly, a marked diurnal pattern of water consumption was reported with little water consumed at night (Howard, 1975).

When Is Water Consumed Relative to Egg-Laying?

In a now "classic" study, Howard (1975) observed a difference in drinking depending on whether an egg was laid that day or not. Water consumption on a day an egg was laid was 225 ml per day per hen, while water consumption on a day no egg was laid was 115 ml per day per hen. This difference in water consumption is due to the increased number of drinks per day. The number of drinks per day on a day an egg was laid was 307 per day per hen, while the number of drinks per day on a day no egg was laid was 146 per day per hen. The difference in water consumption reflects water going to the oviduct and hence the egg, with water in the oviduct (plus egg) rising from 30 to 70 ml during the first 10 hours of egg formation. There is also no difference in the amount of water in the excreta produced per hour:

- Excretion on days of oviposition was 3.9 ml per hour observed between 0930 and 1830 h.
- Excretion on days of no oviposition was 3.48 ml per hour observed between 0930 and 1830 h.

Storage of Water

There should be a system for storage of water (e.g., holding tanks) to meet needs (for drinking and for evaporative cooling) for 48 hours.

17.15 Sanitation

Cleanout requires planning, which includes listing the equipment and labor needed and ensuring their availability. Site preparation includes the following:

- A brush or blower is used to remove dust and any cobwebs from shafts, beams, fan shafts, etc.
- If applicable, spent litter is removed (e.g., by a skip loader).

- Any moveable equipment is removed from the house.
- Equipment, such as automatic waterers and feeders, is winched up.
- A detergent solution is sprayed throughout the house using a low-pressure sprayer.

The house is then cleaned thoroughly before disinfection to eliminate pathogens. Table 17.8 provides a list of commonly used sanitizers. It is very useful to employ a power hose capable of 360° rotation.

Insect Control

A power sprayer can be used for applying disinfectants and insecticides. It is important to ensure that insects are killed before they migrate to within wood.

17.16 Other Processes and Equipment

In modern poultry operations, there are multiple other types of facilities and equipment. These are namely (1) computer(s); (2) control systems; (3) back-up systems, including generators; (4) facilities and equipment for handling spent litter/excreta; (5) facilities and equipment for handling mortalities; and (6) an emergency warning system.

Computers

Computers are a must, for instance, to understand overall profit and loss. Moreover, they are integral to central computerized systems.

Control Systems

There is an obvious need to monitor conditions in the poultry houses. This is to ensure broiler performance and animal welfare, together with air quality for the birds and workers. Among the important conditions to be monitored are (1) the ammonia level in the poultry house, (2) climate control, (3) temperatures within zones in the poultry house, hourly temperature ranges, (4) satisfactory operation of fans, (5) lighting timers, (6) water flow, and (7) feed flow.

Monitoring and control systems are either conventional or computerized (see Figure 17.17). Both systems require detectors/sensors that are regularly checked for accuracy. Thermostats are a simple form of detectors. A central computerized system can monitor the environment in the poultry houses with data from sensors logged at the central location. An advantage of a computerized central system is reduced labor costs. Disadvantages include the initial cost and maintenance.

Growers, farm managers, and hired labor are critical to controlling conditions in poultry houses. Regular visual inspections should include birds, operating fans, and temperature, together with outputs of the various sensors.

Standby Generator

It is very important to have a standby generator(s) in the event of power outages. The first priority is the well-being of the poultry. In warm weather and without ventilation, there are likely to be losses and multi-

Table 17.8 Commonly used sanitizers.

Sanitizers	Forms	Residual Target ppm	Issues
Chlorine	Cl_2 NaOCl (sodium hypochlorite) $Ca(OCl)_2$ (calcium hypochlorite)	3–5 at neutral pH	Oxidized iron Some pathogens are resistant Inexpensive
Chloride dioxide	ClO_2 generated by mixing sodium chlorite ($NaClO_2$) with acid	0.8–2	Effective against chlorine resistant pathogens Expensive
Iodine (sodium iodate)	$NaIO_3$	1–2	Effective Expensive
Hydrogen peroxide	H_2O_2	20–50	Effective Expensive
Ozone	O_3	Unstable	Effective Expensive

Based on Aviagen Turkeys.

Figure 17.17 The environment within poultry houses are tightly controlled to assure both the well-being and optimal production of the poultry.

ple mortalities. The generator can be housed in a shed to protect it from the weather. The shed needs to be ventilated to remove the exhaust gases and to cool the generator. Louvers are effective for this. The generator needs to be inspected regularly to ensure that it is working, there are adequate fuel supplies, and it is free of birds, rodents, and insects. A 100 kw generator uses 3–5 gallons (11.4–18.9 liters) of diesel per hour. It is advised to have a 48-hour supply (144–240 gallons/545–908 liters) on hand in case of emergencies.

Facilities and Equipment for Handling Excreta

The facilities and equipment for handling poultry waste will vary according to the disposition made of it. Among the common animal waste disposal systems and equipment are the following:

1. **Dry spreading**. The spreading of spent litter, dry excreta, or composted litter on cropland is a very common and economical way to dispose of it. The major problems or drawbacks are the land acreage/area required and the odors produced. Spreading must follow all pertinent laws and regulations. A spreader, a pit for storage, and a field(s) are required (see Chapter 11 for details).
2. **Wet spreading**. This refers to excreta to which water is added to create a slurry and facilitate handling. Liquid manure is stored in large watertight storage pits or tanks. For conveying the manure away from the storage tank or pit, either a watertight manure spreader or an irrigation pipe must be available.
3. **Lagoon (anaerobic digestion)**. Outdoor lagoons should be > 3 ft (1 m) deep, and up to an acre in size. They should have outlet mechanisms to control water depth so that there is not overflow into waterways with disastrous environmental consequences. Lagoon effluent is then land-applied.
4. **Incinerators** are expensive, require the use of fuel (usually gas), and may create an odor problem. Some incinerators for poultry waste are used in Europe.
5. **Generation of biogas** (by anaerobic fermentation) is an approach that may be more extensively employed.

Mortalities

Mortalities can be disposed of by composting (see Figure 17.18), incineration, burial on-site or in a land fill, or rendering. Use of these must follow all pertinent laws and regulations. Biosecurity is critically important, particularly in a disease outbreak. If done properly, there are usually no issues of odor, disease, rodent, flies, or water pollution.

Emergency Warning Systems

There are risks with poultry production with mechanically controlled environments. There is a need for both alarms and backup systems, especially for heat for chicks in brooders and ventilation during hot weather. The risks are because of the possibility of (1) power or equipment failure, (2) abnormal temperatures, or (3) fire. To guard against these, an emergency warning system should be installed. Such a warning system may save its cost during just one power interruption, fire, etc. The continuation of the poultry enterprise as the result of a timely warning can be far more valuable than any monetary insurance settlement after the operation has failed.

17.17 Housing and Equipment for Layers

The design and construction of houses and equipment for layers should be such as to provide for egg production with large eggs and high feed efficiency, optimum poultry welfare, satisfactory environmental temperature control (see Figure 17.19), functionality in arrangement of equipment, maximum labor efficiency, satisfactory waste disposal, and minimal housing costs per dozen eggs produced.

Chapter 18 covers layer housing and equipment in more detail. Concrete or slatted floors are widely used in layer houses. The largest changes in layer housing and equipment are shifts in the type of laying system from cage system to colony systems with nest boxes (with or without access to the outside).

Cage System

Early in human development, wild hens were caught and kept in cages in order to facilitate egg gathering. Beginning in the 1930s, commercial layers began to be kept in cages. Today, more than 90% of the layers in the United States are kept in cages, but the percentage is declining. The European Union has restricted use of cage systems.

In the cage system, multiple birds are held in cages. These cages are arranged in long rows in multiple tiers or decks. Where multiple decks are used, the

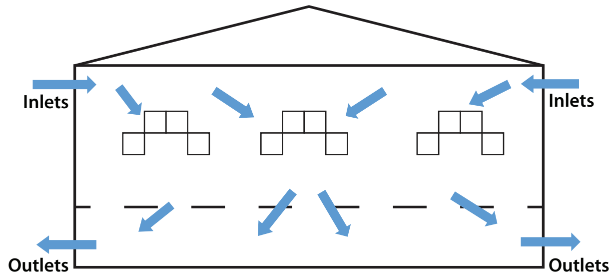


Figure 17.19 Ventilation of a layer house.

A. An example of equipment for composting is the Ecodrum™ composter with temperatures reaching 131°F (55°C) and a rotating drum.

B. After two weeks, composting is complete.

Figure 17.18 Mortalities can be composted with a bulking agent/carbon source, such as wood shavings. Under controlled aerobic conditions, there is low odor and the destruction of pathogens. (Photos courtesy of River Bend Molding Inc. Manufacturer of Ecodrum™ composter)

rows are either located directly above the lower rows or placed so that the bottom row projects forward about one-half the cage's depth, giving a stair-step effect (see Figure 17.20). Excreta falls to below the tiers of cages. There are moves to colony systems with nest boxes (see Figure 17.21). This addresses the demand for cage-free eggs.

Advantages of the cage system are that it accommodates more birds in a given floor area than the litter floor/slatted floor system, reduces the incidence of internal parasites, facilitates egg collection, and there can be enrichment added (see Figure 17.22). The cage system also has issues, including welfare of the layers, consumer concerns, and a high initial investment.

Figure 17.22 Conventional cages for layer chickens enriched with perches (locations indicated by arrows). (Source: Kindly provided by Big Dutchman)

17.18 Brooding and Equipment for Chicks

Wherever chicks are raised, for broilers or replacement pullets, brooding is critically important. Issues include optimal temperature (determined by distribution of chicks and measuring temperature), assuring feeding and drinking begins as soon as possible (determined by feeling for crop fill), sufficient ventilation, and footing such that the chicks can walk easily. Brooding is discussed in more detail in Chapter 16.

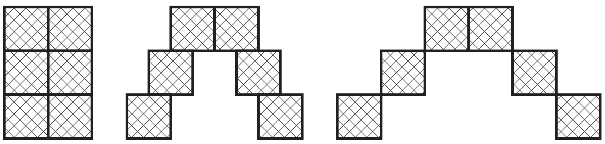


Figure 17.20 Cages for layer hens are placed in three systems: vertically, semi-stepped, or fully stepped.

Figure 17.21 Hens entering a nest box in a colony house. (Source: Kindly provided by Big Dutchman)

17.19 Housing and Equipment for Replacement Pullets

Replacement pullets are an essential prerequisite of egg production. Housing for pullets should provide controlled temperature, ventilation, lighting, and feeders and drinkers. Replacement pullets are raised separated from layers but in the same production system. Pullets are lit (the photoperiod is increased to bring the pullets into lay) after transfer to the layer house.

17.20 Houses and Equipment for Broilers

The general principles for commercial broiler production are the following:

Broiler breeders → Eggs → Hatchery → Chicks →
Grower house(s) → Processing plant →
Grocery store/restaurant → Consumers

Space within a broiler grower house can be designated as brood(er) chamber(s) and grower chamber(s). In commercial broiler production, the bird spends its entire life in one house. Grower houses are thoroughly cleaned and disinfected between flocks. Broiler houses provide dry comfortable surroundings for birds throughout the year: the house is temperature controlled (i.e., kept neither too warm or cool), the litter should be dry, and there needs to be ventilation.

17.21 Houses and Equipment for Turkeys

The general principles for commercial turkey production are the following:

Breeders → Eggs → Hatchery → Poults → Brooder house(s) → Grower house(s) → Processing plant → Grocery store/restaurant → Consumers

Facilities for Breeder Turkeys

Breeding turkeys are maintained indoors, in confinement houses with toms and hens separate. They are housed in environmentally controlled wood or steel tress buildings with aluminum siding. The walls are insulated to reduce the need to heat, cool, and ventilate.

Facilities for Brooding and Growing Turkey Poults

Turkey poults are brooded in brooder houses and moved to grower houses at between 4–6 weeks old to allow increased space (reducing stocking density). Brooder and grower houses are environmentally controlled wood or steel framed buildings with aluminum siding. The walls are insulated to reduce the need to heat, cool, and ventilate. There is an increase in the proportion of grower houses that are tunnel houses. Turkeys are reared separately from all ages of chickens and from adult turkeys.

Brooding requires either a hover brooder or a radiant brooder. Poults are initially maintained at a temperature of about 95°F (35°C) under either a hover or radiant brooder. The temperature is reduced in subsequent weeks. A brooder guard is placed around the poults for the first 1–2 weeks to keep the birds under the brooder, close to feeders and waterers, and to prevent overcrowding in the corners of the house.

Feeders used for baby chicks can be used for brooding poults. Similarly, the waterers (such as nipple waterers with supplementary waterers) can be the same as those used by baby chicks. In grower houses, water is provided by large bell-type waterers and similar large waterers.

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18

Layers and Eggs

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List the major components of eggs.
2. List the major components of egg yolk, egg white, and egg shell.
3. Know how eggs contribute to human nutrition.
4. Know the effects of eating eggs on human health.
5. List the top egg-producing states in the United States.
6. List the major primary breeders of commercial white-egg and brown-egg layers.
7. List the major companies producing eggs.
8. List the major kinds of contracts made with egg producers.
9. List the different kinds of floors used in egg production.
10. Give recommendations on the rearing and production of egg layers and replacement pullets.
11. Know the major costs of a pullet.
12. List the major costs of egg production in order of importance.
13. List procedures for the collection and handling of table eggs to maximize quality.
14. List the uses of eggs in the food industry and what properties of the eggs are used.
15. Know how eggs are used in biomedical science.
16. List the industrial (not food) uses of eggs.

18.1 INTRODUCTION

The commercial production of chicken eggs is of great importance worldwide and is still growing. The impact of the egg industry in the United States alone is estimated to provide 82,000 jobs, $5 billion in wages, $23 billion in economic activity, and $1.8 billion in government revenue (U.S. Poultry & Egg Association, 2016). Little demand for duck eggs exists in the United States. While there is limited quantitative data on duck-egg production or consumption in the world, duck eggs have a large market in China and some other countries in Asia. Moreover, there is significant demand in Western Europe. *Coturnix* (or quail) eggs have a significant niche market, particularly in Europe where high prices are paid for these as shell eggs or pickled hard-boiled eggs.

Egg production and, hence, consumption (and vice versa) are increasing globally (see Chapter 1). Consumption of eggs increased in the United States between 1998 and 2005 (Table 18.1). There was a decline in egg consumption in 2008, the year of the Great Recession, followed by a recovery.

Table 18.1 Per capita consumption of eggs in the United States.

Year	Egg Consumption
1998	240
2001	253
2005	255
2008	248
2011	250
2014	263
2018	289

Data from USDA and UEP.

This chapter addresses the composition of the egg, the biology of the production of the egg by the hen, the commercial production of eggs, handling and marketing eggs, grading and sizes of eggs, and uses of eggs.

Interesting Factoids about Eggs

Humpty Dumpty

Humpty Dumpty is pictured as an anthropomorphized egg, like his appearance with Alice in Lewis Carroll's book *Through the Looking-Glass*. Some consider Humpty Dumpty a rhyme about the death of King Richard III of England (thought to be a hunchback and hence, humpty) at the Battle of Bosworth Field in 1485.

Easter Eggs

According to the writings of Bede (673–735 AD), an English monk, the word "Easter" derives from the name of the goddess Ēostre, whose festival took place in spring and was later replaced by the Christian holiday. Eggs are associated with Easter as a sign of new life, rebirth, and resurrection.

The Etymology (Origin) of the Words Associated with Eggs

Albumen: Derives from two Latin words meaning "white" and "egg."

Embryo: Derives from the Greek "em" meaning "in" and "bruein" meaning "to swell/grow."

Hen: This word comes from the Old English "henn" from the proto-Germanic "hanjō" to Old English (the language of the Anglo-Saxons) from an older word meaning "to sing."

Shell: This word comes from the Old English "scealu" from the proto-Germanic "skaljo" meaning "piece cut off."

Yolk: The word "yolk" derives from the Old English "geolu" meaning "yellow" (formerly spelled "yelk").

So, when we speak of albumen and yolk, we are really saying "the white and the yellow."

18.2 Composition of the Egg

Figure 18.1 depicts the structure of an egg with (1) the shell composed principally of calcium carbonate containing shell covered by the cuticle and a proteinaceous membrane below, (2) the albumen, or egg white, containing the chalaza, and (3) the yolk within the vitelline membrane attached to the outer membranes by the chalaza.

The composition of eggs is considered under the topics yolk, white, and shell.

The Composition of the Yolk

The yolk contains the following:

- Triglycerides (70%) and other lipids, including cholesterol (5%) and phospholipids (25%).
- The phosphoproteins and lipoproteins such as phosvitin and lipovitellin in granules.
- Soluble proteins, such as α-livetin (plasma albumen), ß-livetin (α_2-plasma glycoprotein), and γ-livetin (antibodies or immunoglobulins).
- Binding proteins for nutrients (e.g., riboflavin, biotin, thiamin, vitamin A, vitamin D, iron).

Note: The transfer of antibodies to yolk makes it attractive to produce antibodies in chickens (for vaccines, testing, etc.) because these can be harvested from eggs.

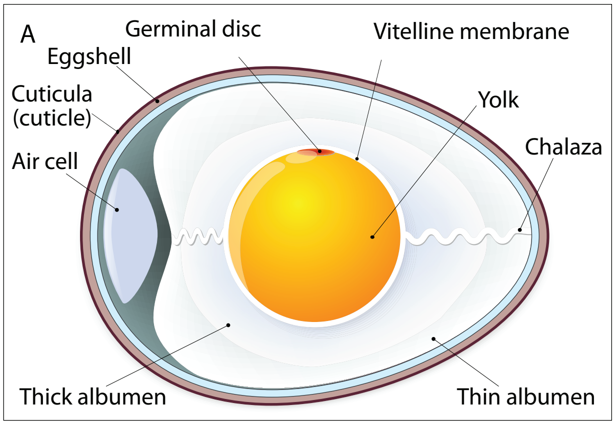
Fat Composition

Much of the fat in eggs is in the form of triglyceride (~10%) together with some phospholipid (~25%) and cholesterol (~5%). The fatty acid composition of egg triglycerides is:

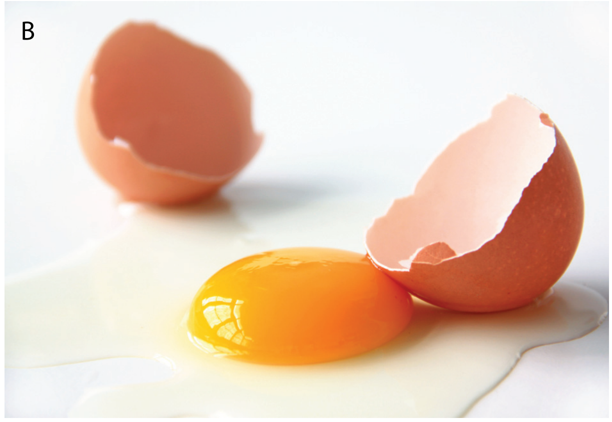
- Monounsaturated about 44% (predominantly 18:1 oleic acid).
- Polyunsaturated about 10% (predominantly 18:2 linoleic acid).
- Saturated about 40% (predominantly 16:0 palmitic acid).
- The composition of egg phospholipids is:
  — Lecithin (containing choline) (~75%).
  — Cephalin (phosphatidylethanolamine) (~20%).
  — Sphingolipids (2.5%).

Cholesterol Content

The cholesterol content of a large egg is 213 mg (this compares to the recommended maximum consumption of 300 mg per day).



A. Diagram of the cross-section of a chicken egg showing shell with cuticle on outside, highly mineralized shell with membrane underneath, albumen or egg white and the yolk contained within the vitelline membrane attached to the outer shell membranes by the chalaza.



B. Cracked egg showing yolk, white and shell of the egg.

Figure 18.1 Structure of an egg. (Sources: A, Designua/Shutterstock. B, famevrs/Shutterstock)

Yolk Pigmentation

The color of egg yolk is dependent on pigments in the diet of the bird. In the United States, the light yellow coloration of the yolk is due to the consumption of pigments such as lutein and ß-carotene coming from marigold petals and yellow corn, respectively. These natural pigments are also nutrients for people, with lutein related to health of the eye and ß-carotene converted to the active forms of vitamin A by the body.

The Composition of the Egg White

The major proteins in the egg white (or albumen) are ovalbumin, 54%; ovotransferrin, 13% (binds iron, zinc, and copper); ovomucoid, 11% (inhibits proteases, e.g., of bacteria); ovoglobulins, 8% (antibodies); lysozyme, 3.5% (an enzyme that lyses or breaks down bacteria); and ovomucin about 2% (antimicrobial). There are also minor components, many of which bind vitamins such as avidin (binds biotin), flavoprotein (binds riboflavin), and thiamine-binding proteins.

The Composition of the Egg Shell

The shell (composed of calcium carbonate in a protein matrix) provides protection from microorganisms and physical damage. In addition, the developing embryo obtains significant amounts of calcium from the shell. This is critical for bone development.

18.3 Nutritional Value of Eggs

Eggs can be an important part of our diets (see Figure 18.2). Eggs are a rich source of nutrients, including proteins containing essential amino acids (see Table 18.2), minerals (e.g., potassium and zinc) (see Table 18.3), and vitamins including vitamin A, choline, B complex, and others (see Table 18.4).

Figure 18.2 A fried egg in a skillet. Eggs are a valuable source of nutrients for consumers. (Source: Shaiith/Shutterstock)

Table 18.2 Composition of eggs.

	Medium	Large	Extra Large	Jumbo
Edible Weight (g)	44	50	58	63
Energy (Kcal)	63	72	80	90
Protein (g)	5.5	6.3	7.0	7.9
Fat (g)	4.2	4.75	5.3	6.0
Saturated	1.37	1.56	1.75	1.97
Monosaturated	1.61	1.83	2.05	2.30
Polysaturated	0.84	0.96	1.07	1.20
Cholesterol (mg)	164	186	208	234
Carbohydrate (g)	0.32	0.36	0.40	0.45
Water (%)	76	76	76	76

Data from the United States Department of Agriculture Agricultural Research Service (USDA-ARS).

In view of the nutritional value of eggs, consumption of eggs by children and the elderly is often recommended.

Definitions

Recommended Dietary Allowance (RDA): The average daily level of intake needed to meet the nutrient requirements of nearly all (97.5%) healthy people.

Dietary Reference Intake (DRI): Represents the best scientific knowledge of daily requirements.

Calories in Foods

- Protein and carbohydrate: 4 Calories per gram.
- Fat: 9 Calories per gram.

Saturated Fat

Nutritionists writing in the *Dietary Guidelines for Americans 2015–2020* recommend that people should consume less than 10% of the calories from saturated fats in their food. For someone consuming 2000 calories per day, this is equivalent to 200 calories (22.2 g) per day from saturated fats. Saturated fat in one jumbo egg (see Table 18.2) is less than 10% of the recommendation ceiling (in fact 8.9% of the upper limit).

Cholesterol and Egg Consumption

Cholesterol is important to the functioning of the body. It is converted to important hormones such as testosterone and estrogen. Moreover, cholesterol is a key component of cell membranes. However, the human body synthesizes enough cholesterol for its needs. Cholesterol is carried in the blood predominantly by two lipoproteins: LDL cholesterol (so-called "bad" cholesterol)—low density lipoprotein, and HDL cholesterol (so-called "good" cholesterol)—high density lipoprotein. High levels of LDL cholesterol (or non-HDL cholesterol) are associated with cardiovascular disease. Eggs contain high levels of cholesterol (see Table 18.2) and in the past this has led people to stop eating eggs. However, there is little evidence to support adverse health consequences from eating eggs. The American Heart Association states:

> Eggs are a good source of protein and other nutrients and can be part of a healthy dietary pattern. Animal products, including eggs, contain saturated fat, which can raise blood cholesterol. Too much bad (LDL) cholesterol in the blood can contribute to formation of plaque and narrowing of the arteries. All the saturated fat is in the yolk. Because egg yolks contain saturated fat, it may be appropriate for people who need to reduce LDL-cholesterol to reduce intake of egg yolks.

Eggs as a Source of Protein

Eggs are a source of high quality protein (meeting the body's need for essential amino acids) and are easily digestible. The amount of protein in eggs of different sizes is shown in Table 18.2. Protein requirements for people are 0.8 grams per kg body weight. This is equivalent to 56 grams of protein for a sedentary man and 46 grams of protein for a sedentary woman. One jumbo egg provides 14.1% of the recommended daily allowance (RDA) of protein for men and 17.2% of the RDA for women of reproductive age (between 19–50).

One large egg is equal to 1 ounce (28.3 g) equivalent of protein. The Healthy US-Style Eating Pattern recommends that the intake for meats, poultry, and eggs be 26 ounce (737 g) equivalents per week (assuming 2,000-calorie intake).

Eggs as a Source of Minerals

Table 18.3 shows the amounts of various minerals in eggs of different sizes. Eggs are a good source of some essential minerals.

Eggs as a Source of Vitamins

Table 18.4 shows the amounts of various vitamins in eggs of different sizes. Eggs are an excellent source of many essential vitamins.

TEXTBOX 18A

A Deeper Dive: Egg Consumption and Cardiovascular and Other Human Health Issues

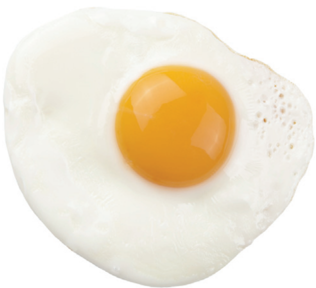
There has been much debate on whether eating eggs is healthy. The available evidence supports the continuing consumption of eggs (see Textbox 18A Figure 1).

Evidence for No Effect on Disease in People

There was no relationship found between egg consumption, up to one egg per day, and coronary heart disease or stroke in either of the following:

- In two meta-analyses of over 3 million person years (people times years) with almost 6,000 cases of coronary heart disease and over 4 million person years and 7,579 cases of stroke (Rong et al., 2013).
- A large prospective study examining the relationship between egg consumption and either cardiovascular disease or stroke (Hu et al., 1999).

Similarly, there was no relationship between egg consumption and either heart attacks (myocardial infarctions) or any type of stroke (Larsson et al., 2015). Moreover, there was no relationship between egg consumption and either cardiovascular disease or mortality from cardiovascular disease (Shin et al., 2013).



Textbox 18A Figure 1 Studies of the impact of eating eggs supports them being part of as healthy diet. (Source: Olga Miltsova/ Shutterstock)

Evidence for Effect on Disease in People

Other studies report that high egg consumption has negative effects. For instance, there was a relationship reported between egg consumption and heart failure in men but only when consumption was greater than or equal to one egg per day (Larsson et al., 2015). Moreover, there was a relationship between egg consumption and cardiovascular disease in people with type 2 diabetes. Egg consumption has also been associated with fatty liver disease (Mokhtari et al., 2017).

Is There a Relationship between Egg Consumption and Cancer?

- No risk of prostate disease (Keum et al., 2015).
- Having over five eggs per week is accompanied by some increase in the risk of breast cancer (Keum et al., 2015).

Evidence for Short-Term Effects on People

There is also evidence from short-term studies of positive effects of egg consumption. A short-term study (DiMarco et al., 2017a; 2017b) compared biochemical and other clinical parameters in young healthy people consuming zero, one, two, or three eggs per day, with the following found with increasing egg consumption:

- Diastolic blood pressure decreasing with egg consumption.
- Increased plasma/serum concentrations of the important nutrients, choline, lutein, and zeaxanthin.
- Increased HDL (good) cholesterol and large HDL particles.
- Decreased LDL (bad) cholesterol and large LDL particles.
- Trimethylamine-N-oxide (TMAO).

In another study (Missimer et al., 2017), the results indicate that eating eggs reduces the amount of food that young people eat with no effects on biomarkers of cardiovascular disease. When consumption of two eggs for breakfast each day were compared with having oatmeal, the following were observed:

- Increases in both HDL and LDL but no difference in the ratio of LDL to HDL (a biomarker for the risk of cardiovascular disease).
- Increased satiety (feeling of fullness).
- Reduced plasma concentrations of ghrelin (a critical stimulator of eating).

Similarly, there is evidence that consumption of eggs is followed by a reduced intake of food and improved the response to a glucose challenge (Ratcliffe et al., 2010).

TEXTBOX 18B

A Deeper Dive: Mineral Requirements and How Eggs Meet This Requirement

Looking at the data from Table 18.3 and Textbox 18B Table 1, we see that one jumbo egg meets the following RDA amounts in men: 5.0% Copper, 7.3% Iron, 34.5% Selenium, and 7.4% Zinc. One jumbo egg meets the following RDA amounts in women of reproductive age (between 19–50): 5.0% Copper, 6.1% Iron, 34.5% Selenium, and 9.9% Zinc.

Textbox 18B Table 1 Recommended daily allowances for some minerals.

Age/Life Stage	Copper mg per Day	Iron mg Day^{-1}	Selenium µg Day^{-1}	Zinc mg Day^{-1}
Children 9–13 yrs.	0.7	8	40	8
Men/Women over 50	0.9	8	55	11
Women 19–50 yrs.	0.9	18	55	8
Pregnant women	1.0	27	60	11
Lactating woman	1.3	9	70	12

Data from National Institute of Health, Office of Dietary Supplements.

Table 18.3 Mineral composition of eggs.

	Medium	Large	Extra Large	Jumbo
Phosphorus (P) (mg)	87	99	111	125
Sodium (Na) (mg)	62	71	80	89
Potassium (K) (mg)	61	69	77	87
Calcium (Ca) (mg)	25	28	31	35
Magnesium (Mg) (mg)	5	6	7	8
Iron (Fe) (mg)	0.77	0.88	0.98	1.10
Zinc (Zn) (mg)	0.57	0.65	0.72	0.81
Manganese (Mg) (µg)	12	14	16	18
Copper (Cu) (µg)	32	36	40	45
Selenium (Se) (µg)	13	15	17	19

Data from USDA-ARS.

Table 18.4 Vitamin content of different sized eggs.

Vitamin	Medium	Large	Extra Large	Jumbo	Requirement per Day
Water soluble					
Choline (mg)	129	147	164	185	425/550
Pantothenic acid (mg)	0.675	0.766	0.858	0.966	5/5
Riboflavin (µg)	201	229	256	288	1100/1300
Vitamin B_6 (Pyridoxine) (µg)	75	85	95	107	1300/1500
Niacin (µg)	33	37	42	47	1400/1600
Thiamin (µg)	18	20	22	25	1100/1200
Folate (µg)	21	24	26	30	400/400
Vitamin B_{12} (µg)	0.39	0.45	0.50	0.56	2.4/2.4
Fat soluble vitamins					
Vitamin A (IU)	238	270	302	340	2333/3000
Vitamin D (IU)	36	41	46	52	600/600
Vitamin E (mg)	0.46	0.53	0.59	0.66	15/15
Vitamin K (µg)	0.1	0.1	0.2	0.2	90/120
Lutein + zeaxantin (µg)	221	252	282	317	—

Data from USDA-ARS and Dietary Reference Intakes (DRIs) from the National Academies.

18.4 Biology of the Production of the Egg

Yolk

The liver of the hen synthesizes the precursors of yolk, namely the phospholipoprotein vitellogenin. The very low-density lipoproteins (VLDLs) are rich in triglycerides. Estrogens, and possibly other hormones, are required for the synthesis of the yolk precursors. They pass via the bloodstream to the developing follicles in the ovary (see Chapter 4) where they are deposited in the ovum (as yolk). The vitellogenin molecules are split to yield lipovitellins and phosvitin.

Egg White (Albumen)

The oviduct produces the egg white proteins. Most of this occurs in the magnum region. The process is predominantly under the control of estrogens (e.g., estradiol). An exception to this is avidin, where progesterone is the major controlling hormone.

Shell

The oviduct produces the shell (made up of calcium carbonate). This occurs in the shell gland. The process involves the transfer of calcium from (1) the feed in the intestines to the shell via the blood and (2) from the bones to the shell, again via the blood (see Figure 18.3). Hormones are important to the process.

Textbox 18C

A Deeper Dive: Composition of Eggs

It is often assumed that eggs have the same composition. Broadly this is true; eggs have yolks, white, and shells. However, there are shifts in composition as determined, for example, by Dong Ahn's laboratory at Iowa State University. Firstly, there are differences in the ratio of yolk to white in eggs with size and stage in laying. A progressive decrease in the ratio of yolk to white was reported with increasing egg size (see Textbox 18C Table 1). Moreover, there were marked shifts in the egg yolk to white ratio during stage of egg laying, with an increase during mid-lay followed by a decrease towards the end of lay (see Textbox 18C Table 2) (Ahn et al., 1997). This might suggest that eggs from different stages of lay should be used for table eggs versus liquid eggs.

Similarly, there are shifts in egg composition with some nutritional regimens. Feeding conjugated fatty acids (CLA) is followed by increases in conjugated fatty acids (cis-9, trans-11 CLA; trans-10, cis-12 CLA; cis-8, trans-10 CLA; and cis-11, trans-13 CLA) and decreases in both linoleic acid (9,12-octadecadienoic acid) and oleic acid (9-octadecenoic acid) in yolk lipid (Du et al., 1999). The addition of both vitamin C and E to hen diets decreases the concentration of yolk malondialdehyde (MDA) in the yolk; MDA being a marker of oxidative stress (increase in free radicals) (Irandoust and Ahn, 2015). Vitamin E supplementation of the laying-hen feed also increases vitamin E content of the eggs (Irandoust and Ahn, 2015).

Textbox 18C Table 1 Differences in egg composition with egg size.

Egg Size	Yolk:White Ratio	Number of Eggs Tested
Medium	45.4^{a}	850
Large	43.8^{ab}	1346
Extra Large	41.9^{b}	1293
Jumbo	39.4^{c}	626

^{a,b,c} Different superscript indicate statistical difference $p < 0.05$.

Textbox 18C Table 2 Differences in egg composition with stage of lay.

Egg Size	Yolk:White Ratio	Number of Eggs Tested
Early in lay (28 weeks old)	36.6^{c}	655
Mid lay (55 weeks old)	46.4^{a}	818
Mid lay (78 weeks old)	46.6^{a}	1156
Late in lay (97 weeks old)	40.8^{b}	1486

$^{a, b, c}$ Different superscript indicate statistical difference $p < 0.05$.

Data from Ahn et al., 1997.

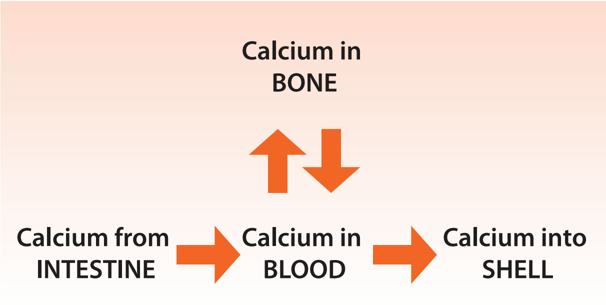


Figure 18.3 Movement (fluxes) of calcium in the body of the hen.

Table 18.5 Ranking of US states by egg production in 2017.

Rank	State	Number of Eggs Produced (in millions)
1	Iowa	15,953
2	Indiana	9,582
3	Ohio	8,904
4	Pennsylvania	8,213
5	Texas	5,761
6	Georgia	4,964
7	Michigan	4,225
8	North Carolina	3,935
9	California	3,759
10	Arkansas	3,377

Data from USDA-NASS.

18.5 Overview of Commercial Egg Production

The commercial production of eggs is important worldwide. In the United States, the top egg-producing states largely stretch across the corn-belt of the US; namely Iowa, Indiana, Ohio, and Pennsylvania (see Table 18.5 and Figure 18.4). In North America, over 90% of the layers are in cages or on wire (see Table 18.6), and replacement pullets are largely brooded and reared in cages from one day old to reduce labor requirements and provide greater efficiency. There is an increase in the production of free-range and organic eggs in North America and, particularly, in Western Europe. In 2017, eggs produced in organic systems reached 5% of total production in the United States (see Table 18.6).

Egg production is predominantly undertaken by large companies. The following were the top US egg-producing companies by the end of 2017 (data from WattAgNet).

1. Cal-Maine Foods (headquarters in Mississippi) with 41.1 million hens.
2. Rose Acre Farms (headquarters in Indiana) with 26.9 million hens.
3. Hillandale Farms (headquarters in Pennsylvania) with 16.73 million hens.

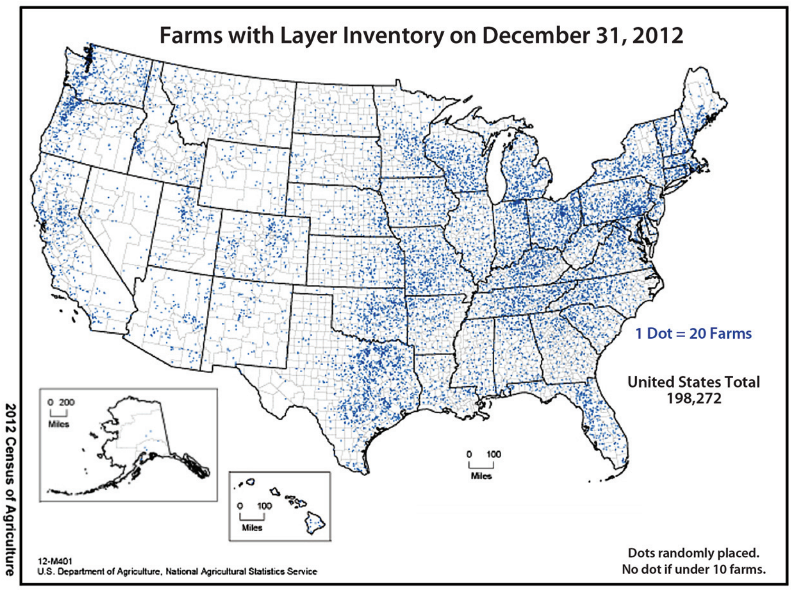


Figure 18.4 Distribution of egg production in the US based on the latest USDA information on the number of farms with laying-hen inventory. Each dot shows 20 layer farms. (Source: USDA)

Table 18.6 Types of production of eggs in the United States in 2017.

Type of Production	Percentage of Egg Production
Conventional	84
Cage-free	11
Organic	5

Data from USDA-NASS and UEP.

4. Versova Holdings (headquarters in north central Iowa and central Ohio) with 16.4 million hens.
5. Daybreak Foods (headquarters in Iowa) with 12.8 million hens.
6. Rembrandt Enterprises (headquarters in Iowa) with 12.5 million hens.
7. Michaels Food (headquarters in Minnesota) with 12.18 million hens.
8. Center Fresh Group (headquarters in Iowa) with 9.7 million hens.
9. Midwest Poultry Services L.P. (headquarters in Indiana) with 9.5 million hens.
10. Prairie Star Farms (headquarters in Ohio) with 9.4 million hens.

TEXTBOX 18D

A Deeper Dive: Egg Production

Largest companies producing eggs in the World in 2016 (data from WattAgNet):

1. Cal-Maine Food Inc. (US) with 41.1 million layers.
2. Proteína Animal (PROAN) (Mexico) with 33 million layers.
3. Rose Acre Farms Inc. (US) with 26.9 million layers.
4. Ise Inc. (Japan) with 20.0 million layers.
5. Hillandale Farms (US) with 16.73 million layers.
6. Versova Holdings (US) with 16.4 million layers.
7. Arab Company for Livestock Development (ACOLID) (Saudi Arabia) with 13.4 million layers.
8. Michaels Food Inc. (US) with 12.2 million layers.
9. Industrias Bachoco (Mexico) with 12.2 million layers.
10. CP Foods (Thailand) with 12 million layers.

Egg Production

The production of table eggs or eggs is divided into (1) production of replacement or starter pullets, which involves brooding and rearing of chicks until they are old enough to start egg production (discussed in Section 18.8) and (2) production of eggs by layer hens (discussed in Section 18.7).

These two phases of production are usually carried out at different locations some distance apart in order to reduce the incidence of infectious diseases. An additional phase is processing and marketing of eggs (discussed in Section 18.9). Large egg producers do the entire job of egg production, processing, and marketing, with their eggs trucked directly from their egg-holding room facilities to the store door.

Definitions

One cycle: In the one-cycle system, pullets are brought into production, egg production peaks and then declines, and once egg production reaches a noneconomic rate, birds are killed and new pullets are brought into the layer house after the cages/house are washed and disinfected. One cycle has birds in the layer house from 20 to 90 weeks.

Two cycle: In the two-cycle system, pullets are brought into production, egg production peaks and then declines, and once egg production reaches a noneconomic rate, hens are molted and then brought back into production. In the second cycle, egg production rebounds to a level much greater than before molt. The second cycle is shorter than the first. Two cycle has birds in the layer house from 20 to 120 weeks.

Business Aspects of Egg Production

Commercial egg production is large and intricate. It would be unusual for anyone to start a commercial egg enterprise with fewer than several hundred thousand birds. With the increase in size and complexity of units, the business aspects have become more sophisticated. It is important, therefore, that commercial egg producers be knowledgeable in financing, labor requirements, contracts, recordkeeping, and costs and returns.

Location

Determining where to locate laying units requires consideration of the competitive advantages and disadvantages of the location. Factors include the costs of land, buildings, and feed (proximity to corn and soybean production will likely result in lower costs and the ability to contract for long-term supplies while having access to land for application of animal waste);

the higher prices of corn in the Southeast and South Central United States compared to the Midwest; labor availability and costs; meeting requirements of local, state, and federal regulations; and access and proximity to markets.

Financing

One of the first things to consider when thinking of becoming a commercial egg producer is how much money it will take and where the money will come from.

Fully Vertically Egg Production

Many eggs are produced in fully vertically integrated operations with the same company owning the poultry houses, the birds, and marketing the eggs. The company may also raise the pullets and process the feed.

Egg Contracts

Reasons for producers contracting production and/or marketing include narrowing profit margins, fluctuating egg prices, expanded flock size, the large investment, and a desire for a stable income. Contracts may cover management of layers (feed, space, animal health program, biosecurity, etc.), strain of birds and replacement pullets, months of lay (production and quality), and quantity and quality of eggs to be delivered. The types of egg contracts include producer contracts, credit contracts, and marketing contracts.

In egg contracts, producers usually own the buildings and equipment and furnish labor, management, and utilities in return for a fixed rate per layer per week or per dozen top-grade eggs produced. Contractors usually furnish hens, feed, animal health programs, supervision, and a market for the eggs. In some areas, the contractors haul the eggs; in others, the producers do the hauling. Generally, the producer only washes the dirty and badly stained eggs.

The terms of contracts vary among areas and are affected by the amount of competition and the level of commercial egg prices. The following types of egg production contracts are rather typical:

- **A fixed fee per dozen eggs**. The producer furnishes housing, equipment, labor, utilities, and sometimes litter and receives a payment per dozen eggs produced. The contractor furnishes ready-to-lay hens, feed, medication, and owns all eggs as well as the salvage hens at the end of the production period. There may be bonuses for good feed conversion, egg quality, or low mortality.
- **A fixed fee per hen per month**. The producer furnishes the same items as in the above contract, but is paid per hen rather than per unit eggs.
- **Percentage of returns**. The producer furnishes the items listed in the first type of contract and receives a percentage of the total egg returns (usually averages 15–18%). The feed supplier usually receives 50–55% of the return, while the supplier of the ready-to-lay pullets gets 26–28% (usually retains ownership of birds). The percentage received by any party must be proportional to the contribution in the form of material and/or services.

Recordkeeping and Production Goals

Keeping and using performance records are vital to success in egg production. It is critical to compare the records with production goals from the breeding company. The following records are important:

- **Feed consumption**. This is critical to determine profitability. Also, if there is decreased feed consumption, this may predict a problem and precede a drop in the egg production.
- **Number of eggs produced** per day, week, month, etc.
- **Egg quality and egg size**. The goal should be at least 90% or more Grade A, fewer than 5% small eggs, and fewer than 20% medium eggs. Large or extra-large Grade A or AA have the most potential for profit.
- **Mortality**. The producer should keep records of daily, weekly, and cumulative mortality and morbidity where culling is necessary.

Costs and Returns

As in any business, profits in egg production can be increased by either (1) lowering costs or (2) increasing returns, or both. Feed is one of the largest costs. Others include labor, interest, and depreciation. Eggs are the chief source of returns on a commercial egg farm.

The cost of producing eggs varies with location and is primarily based on the cost of feed ingredients. Estimated costs related to 42¢/dozen eggs are the following: feed (48%), replacement pullets (22%), housing and equipment (11%), labor (8%), and miscellaneous (11%). Some production costs can be lowered. The place to start is the highest-cost items—feed, pullets, and labor. These account for about 80% of the cost of production. Labor costs can be lowered with good personnel management and automation.

Returns can be increased; egg prices fluctuate widely and wildly! Profits range from nonexistent (or losses) to very high. Returns from commercial egg production can be improved by more eggs per bird and improved egg quality by adjusting lighting, feed, and animal health programs. Increased production of 24 eggs per bird in a 300,000-bird unit would increase income by $360,000 (at 60¢ per dozen). Yet costs will be the same.

Breeding and Genetics

Selection of superior genetics is extremely important. Continuous improvement is being made in breeding. A single company, Hy-Line International, dominates the US market with more than an 85% market share (44% of the global market). On the other hand, three companies dominate the world market (for examples of hens see Figures 18.5 to 18.7).

Breeders produce and sell "name lines" such as the following:

- Hendrix Genetics brands: ISA, Shaver, Hisex, Dekalb, Bovans, and Babcock (Hubbard-ISA).
- Hy-Line (Hy-Line) is part of the EW Group GmbH; a holding company based in Visbek, Niedersachsen (Lower Saxony), Germany.
- Novogen (the layer genetics division of Groupe Grimaud).

In-bred lines are crossed to produce the commercial chick or breeders. Each line or strain of a breeder carries a brand name and number for identification that is similar to the makes and models of automobiles. Issues to consider in purchasing pullets (point-of-lay hens) include the egg production and quality, feed efficiency (smaller hens tending to high feed efficiencies), livability (or low mortality), and service from the primary producer/supplier.

Replacement Pullets

Poultry production involves specialization and more specialization. Some commercial egg producers only produce eggs, while others rear replacement pullets. Some are integrated and do both. The commercial egg producer has two alternatives in procuring replacement stock: day-old female chicks (vaccinated) or ready-to-lay pullets (or point-of-lay) (~19 weeks of age). Biosecurity and animal health programs are integral to both layers and pullets.

Day-Old Chicks/Pullets

The key to effective layers is genetics, egg production, egg size, feed efficiency, low mortality, suitability to their environment (cage or aviary conditions), and reliability and reputation of the hatchery. Price should be one of the least important considerations when buying day-old chicks for raising replacement pullets.

Replacement Programs

When the average rate of lay falls below 65%, commercial egg producers can choose to either cull and use replacement pullets or induce molting. The replacement program that egg producers choose is an important management decision. It depends on costs, returns, and the issue of welfare (discussed in more detail later). Excluding capital costs, replacement pullets represent the second largest cost of producing eggs (feed is first).

All-Pullet Flocks

An all-pullet flock is made up of birds that are less than 6 months old when the production year starts. In comparison with hens, pullets have the following advantages:

- Lay 30% more eggs during their second year of production.
- Require less feed to produce a dozen eggs.
- Pullet eggs have a higher interior quality (a high percentage of thick white compared to thin white).
- Lay eggs with stronger shells.

The all-pullet system is used in North America. There is a growing interest in the system in Europe where welfare regulations are moving to limit forced molting. All-pullet flocks are easy to manage. Once a cutoff age is selected, new pullets can be used at routine intervals. The only real problem is to determine the point at which total profits will be maximized.

Egg producers choose a wide range of cutoff ages of all-pullet programs, from as short as 50 weeks of age at sale to as long as 108 weeks, with an average of about 82 weeks. At the 82-week (20-month) age, most flocks are at 50–55% production; the number of "undergrade" eggs (egg quality and size is discussed later in this chapter) approaches 20%, and the flock size is approximately 80% of the number originally housed due to mortalities.

Molting

Molting is a natural process of shedding and developing new feathers and is followed by increased egg production. Molting occurs in the following order: head, neck, body (including breast, back, and abdomen), wing, and tail. The birds shed their feathers annually at the end of the breeding season. Hens seldom lay and shed feathers at the same time. A high-producing bird may, for a time, molt and lay simultaneously, but usually she is in declining production

Figure 18.5 The Hy-Line W-36 is an industry standard of a white-egg layer used in commercial egg production. (Photo courtesy of Hy-Line International)

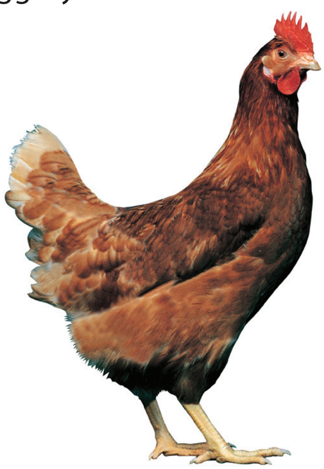
Figure 18.6 The Hy-Line Brown is an example of a brown-egg layer used in commercial egg production. (Photo courtesy of Hy-Line International)

SHAVER WHITE
white egg layer

DEKALB WHITE
white egg layer

BOVANS WHITE
white egg layer

ISA BROWN
brown egg layer



BOVANS BROWN
brown egg layer

Figure 18.7 Hendrix Genetics layer hens. (Source: Hendrix Genetics) when molting begins. Egg-type birds have been bred so intensely for egg production that some continue to lay rather than molt. Producers interested in obtaining a second cycle of egg production may induce molt and a rest from laying.

Induced molting is accomplished by reducing the available feed and reducing the day length. The poultry industry has reacted to public concerns/activist pressure by shifting to nonfeed withdrawal methods to induce molting. This is achieved by a variety of techniques that all involve shifting to both a short daily photoperiod and feed that provides reduced nutrition, e.g., energy, protein, and/or specific minerals. Water must be provided during this time. Molting is induced when egg production is slowing and is no longer economic for the producer. Molting reduces the overall costs of replacement pullets on a per dozen egg basis (see Table 18.9). In general, higher net replacement costs with pullets and lower egg prices tend to favor the use of induced molting.

Advantages of induced molting include low replacement costs of pullets, greater production (peaking at 85%), improved egg quality and shell quality, continued high egg size and lack of the small or medium eggs produced by new hens early in the first cycle. Disadvantages of induced molting include the possibility of increased mortality (~1.5% of the flock during the resting period or time of induced molting) and considerable interest from people concerned about animal welfare and consequently the potential loss of consumer confidence in the product.

Should a Producer Use Recycling or Use Replacement Pullets?

It depends on a variety of economic factors including the following:

- Recycling becomes more profitable as egg prices decrease.
- As the cost of replacement pullets increases, it becomes more advantageous to recycle.
- What is the projected price of feed for laying period compared to during recycling?
- High differential between prices for larger eggs favors recycling.
- The profitability of recycling increases as the price paid for old layers (spent hens) decreases if there is even a market for spent hens. The market for spent hens continues to diminish at a rapid rate. Spent hens are increasingly disposed of by composting (preferred) or by rendering.
- Using replacement pullets instead of recycling ties up capital.
- There are welfare issues related to some methods of induced molting and the issue can be used by activists.

18.6 Management of Layers

Key Management Decisions

Management involves decision-making. Many of the decisions egg producers make are only made once; hence, they had better be right. Among the layer management decisions that must be made are:

- Whether to go into egg production and where.
- Method of financing.
- Contract versus independent production.
- The breed and breeding; and whether to buy or raise replacement pullets.
- System type and size of house and equipment.
- The diet to use; and whether to buy commercial feed or home-mix.
- The flock health program.
- Biosecurity plan.
- The marketing plan for eggs.

Additionally, the capable manager sets high production goals and is quick to sense when all is not well in the hen house and how to rectify the situation.

Production Goals

Producers of commercial eggs strive for the maximum of egg production at a minimum cost, yet they recognize that net returns are more important than costs as such. The largest item of cost in the production of eggs is feed. It normally constitutes 50–70% of the total cost. Labor costs and cost of replacement pullets are the other two major cost items in production. Generally speaking, higher egg production means lower costs per dozen eggs. This is because the feed required for maintenance is constant for hens of any given weight and bears no relation to the number of eggs laid. Hence, it is important that commercial producers strive for high egg production. The production cycle for egg production is shown in Figure 18.8.

The following production goals (e.g., Hy-Line W-36) are suggested for the commercial egg producer:

- 50% egg production: 20.5 weeks.
- Egg production peak: 95–96%.

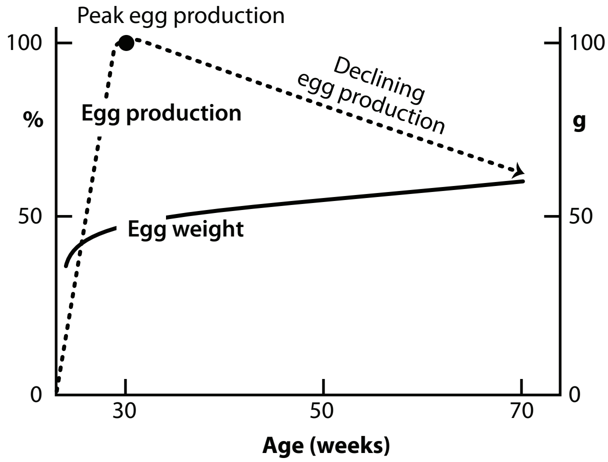


Figure 18.8 The laying cycle of a hen with egg production increasing after photostimulation (due to increasing day length), peaking and then gradually decreasing. Egg weight increases during the laying cycle. Birds can be induced to molt and cease egg production. After this, egg production returns to a higher rate with large egg size continued.

- Eggs produced to 60 weeks: 258.
- Eggs produced to 90 weeks: 426.
- Eggs produced to 110 weeks: 510.

Also there are goals for egg-white quality (see Table 18.7) and egg weight (see Table 18.8).

- Feed conversion ratio (kg: kg) 20–60 weeks: 1.85.
- A laying house mortality of less than 10%.
- More than 75% extra-large and large Grade A eggs.
- More than 95% marketable eggs.
- On-farm egg breakage under 2%.

Size does not assure success and profitability in commercial egg production. Rather, it makes it imperative that there be superior management and adequate ventilation. Production costs increase with some aviary systems (see Textbox 18F) and with the provision of enrichment.

Table 18.7 Goals for egg-white quality reflecting changes in egg quality during the egg-laying cycle.

Age (Weeks)	Egg White (Haugh Units)
38	91.4
56	87.5
70	86.0
80	85.0

Based on Hy-Line International.

Table 18.8 Goals for egg weight reflecting changes in egg size during the egg-laying cycle.

Age (Weeks)	Egg Weight (g)
26	57.1
32	59.7
70	63.6
110	63.9

Based on Hy-Line International.

Economics of Laying Hens

Table 18.9 shows differences in costs between one- or two-cycle production in the United States. This is based on feed costs in early 2018 (corn $178 per US ton [$3.88 per bushel]; soybean $382 per ton [$10.42 per bushel]). With lower prices for corn and soybean, the two-cycle system would be more advantageous to producers. In contrast, with higher prices for corn and soybean, the one-cycle system would seem be more advantageous to producers. However, the cost to raise pullets also declines. Retail prices for large eggs were $2.10 in early 2015 ($1.93 in 2013; $2.05 in 2014).

Table 18.9 Production costs expressed per dozen eggs.

	Egg Industry Center study (2015)		Analysis by Don Bell in 2003/4 [a]
Costs/Profit	**One Cycle**	**Two Cycle**	
Feed	$0.35	$0.38	$0.25
Pullet	$0.11	$0.08	$0.07
Other	$0.17[b]	$0.17[b]	$0.13[c]
Total	$0.63	$0.63	$0.45
Profit	**$0.42**	**$0.42**	**$0.13**

[a] Assumes production of 34 dozen eggs per hen (408 eggs) and 3.45 lb (1.57 kg) feed required per dozen eggs.
[b] Costs for labor, buildings, equipment, interest, and miscellaneous estimated as 17.15 cents per dozen (all regions of the US except California).
[c] This consists of labor $0.03, depreciation on buildings and equipment $0.03, interest $0.02, and other costs $0.05.

Biosecurity

Biosecurity is essential for successful poultry production. This is to minimize risks from pathogens such as *Salmonella*, *Mycoplasma*, highly pathogenic avian influenza (HPAI) viruses, or other infectious agents. The outbreak of HPAI in the United States in 2015 cost over $1 billion. Wild birds, particularly ducks, are reservoirs for AI viruses and sources for many poultry pathogens. It is essential that poultry do not come into contact with wild birds. Other mechanisms for the spread of pathogens include the movements of vehicles, equipment, and dead birds contaminated with pathogens; aerosol droplets and dust particles contaminated with pathogens; and personnel contaminated with pathogens.

Proximity (closeness) is one of the most important issues in the spread of any pathogens. This is applicable to the physical distance to wild birds, rodents, and insects; any personnel with backyard poultry or visiting such birds; and shared equipment, vehicles, etc., between different units. With closer proximity, such as with other commercial poultry houses or backyard flocks, the biosecurity plans must be even more rigorous. Among the recommended practices to assure biosecurity are the following:

- Each layer or pullet facility should have a biosecurity officer and biosecurity training for all personnel.
- The biosecurity plan must describe standard operating procedures (SOPs). These include sanitation (cleaning and disinfection of buildings), equipment and vehicles, protective clothing provided for personal (ideally employees should shower and change clothes before entering layer or pullet houses), boot-washing stations, quarantine procedures, and ensuring limited access to the facility.
- Wild birds, rodents, and insects should be excluded from layer/pullet housing to protect the birds from pathogens.
- External bird sources should be from certified flocks and free of primary poultry diseases.
- Water should be either city/mains (chlorinated water) or from deep wells (and tested).

Training of Personnel

Training of personnel is essential. Areas for training include biosecurity, proper handling of birds, company policy related to cruelty, humane euthanasia, beak trimming, and worker safety.

Personnel Duties

Check on the following:

- Are there mortalities? (These need to be noted and removed.)
- Are there injured birds? (These need to be culled, noted, and removed.)
- Do the birds look normal and are they showing normal behaviors?
- Is feed and water available to all hens?
- Are lights working?
- Are fans working and is air moving?

Excreta (Animal Waste)

One of the major problems on a large egg farm is the disposal of the excreta. The best solution is to spread it on fields as fertilizer. Some producers handle excreta as a liquid. The animal waste is naturally degraded in anaerobic lagoons with a loss of nitrogen (nitrogen gas plus some ammonia) and carbon (carbon dioxide and methane) to the air. The liquid can then be land applied. Alternatives exist for producers who encounter odor or regulatory problems. These include in-house drying, since excreta dried to 30 to 50% moisture has little odor; composting; and incineration. A combination of regular removal, hauling, and spreading is a good policy. Spreading in the winter may not be possible when land is frozen. Similarly, summer application may be precluded by the presence of growing crops.

18.7 Layer Production

Even though routine, certain management practices are prerequisites to success in egg production; among them, beak trimming, lighting, animal waste/excreta handling, culling, nesting, broodiness, and dubbing. Figure 18.8 shows the egg-laying cycle. Egg production increases rapidly after photostimulation. After peak production is reached, egg production declines gradually. Hens are held in either cages or aviary systems.

Lighting

Temperate zone birds, including laying hens, usually reproduce in the spring as day length increases. After cessation of egg production, birds molt, and later regrow feathers. Poultry producers have taken advantage of reproduction being induced by long daily photoperiods and have effectively given a perpetual spring for the hens that results in year-round egg production.

Pullets are brought into lay by increasing the day length. Pullets are grown under short daylight to 19 or 20 weeks of age. Pullets should be photostimulated (by increased day length) at about 18 weeks and once the target body weight is met. This is achieved by an increase in the photoperiod by one hour every week until 16L:8D is reached, and an increase in light intensity to either 15–30 lx (1.5–3.0 FC) in light-controlled houses or 30–40 lx (3–4 FC) in open-sided houses.

In some light schemes for laying hens there is a night interruption with daylight to allow nocturnal eating or so-called "midnight snacks" to increase overall feed intake (see Figure 18.9).

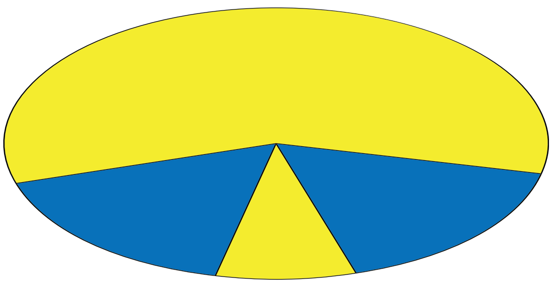


Figure 18.9 Interruption of the subjective night by light period increases feed intake in laying hens in the system known as midnight feeding.

Nutrition

Nutrition plays a major role in the ability of birds to produce quality eggs and to assure the health of the flock due to the ability of the hens to resist diseases. Feed is by far the greatest expense item in producing eggs. Therefore, the efficient producer uses a feeding program that maximizes profit. An example of a layer feed is 67% corn, 22% soybeans, 8% limestone (calcium carbonate), and 3% other.

A layer ration must furnish an adequate supply of nutrients. The essential nutrients are adequate energy, furnished by starches and fats; protein (with the optimal balance of amino acids, particularly limiting essential amino acids); necessary minerals; and sufficient vitamins. The diet must be formulated to meet or exceed the breeding company's stated or established requirements and be broadly consistent with National Research Council (NRC) recommendations. Producers can buy their feed commercially prepared, they can mix locally grown grain either with commercial supplements or individual ingredients, or they can do on-farm mixing, especially the large producers. It should be remembered that feed mixing is complex and exacting and should be attempted only by those persons who are knowledgeable. Also, regardless of how poultry feed is obtained, it should be formulated and mixed correctly (also see Chapters 6 and 7).

Feed during Pre-Lay Phase

There are both quantitative and qualitative changes in nutrition as laying hens come into lay including the following:

- During the pre-lay phase, the feed should contain at least 2.5% calcium to build up calcium in the long bones and specifically the medullary bones (see Figure 18.3).
- Food intake increases immediately prior to egg laying and while laying.

Feed intake increases markedly (e.g., 60 g per day to 100 g) as the pullets come into lay.

Feed during Late Lay Phase

Consider the following:

- Re-formulate feed based on feed consumption.
- Increase calcium in the feed to a concentration of 2.5% 10 days before the expected time of first egg.
- Increase vitamin D and 25-hydroxy vitamin D_3.
- Increase consumption of organic (chelated) trace minerals [organic zinc (Zn), manganese (Mn), and copper (Cu)].
- Replace some salt (NaCl) in the diet with sodium bicarbonate ($NaHCO_3$).

Feed during Heat Stress

During heat stress, the following changes to the layer diet are made:

- Increase 25-hydroxy vitamin D_3 in the feed.
- Increase consumption of organic (chelated) trace minerals [organic zinc (Zn), manganese (Mn), and copper (Cu)].
- Replace some salt (NaCl) in diet with sodium bicarbonate ($NaHCO_3$).

Feeding Programs

Egg producers use an all-mash diet. Commercial egg producers use this feeding program exclusively.

Under this program the operator uses a complete feed—a must when a mechanical feeder is used. It may be fed meal, granules, and crumbles of various sizes. An all-mash program offers the greatest assurance of good production. Also, it comes closest to ensuring uniform yolk color. A 14–17% protein mash is recommended for layers.

Poultry Health for Layers

Mortality or morbidity are critically important to top commercial egg producers as they are indicative of problems and also take away productive/potentially productive units. Any drops in egg production or in daily feed consumption may indicate the need to check flock health and take corrective action. All chickens are susceptible to diseases resulting from stress (e.g., poor nutrition and environment) and/or infections. The following points are important:

- Purchase/transfer healthy, disease-free replacement pullets stock.
- Minimize stress.
- Follow precise vaccination program.
- Ensure biosecurity. Keep visitors away from poultry buildings. Do not mix birds of different ages. Never permit contaminated equipment from other poultry farms on facility. Screen poultry houses so wild birds and rodents cannot enter.
- Remove sick, injured, and dead birds as soon as noticed (burn, compost, or bury dead birds immediately).
- Ensure clean water of a high quality. Test water quality. Clean trough-type waterers daily. Check operation of individual cups and direct-action valves or nipples.
- Check operation of feeders, fans, and lights.
- Work closely with the poultry veterinarian and their recommended drugs or biologics.
- Maintain good records on flock health.

The five key components in any disease prevention program are sanitation, nutrition, environmental quality, vaccination, and parasite control.

Sanitation is essential. This includes everything the birds or eggs come in contact with. Clean, disinfect, and air out a poultry house before putting birds of any age in it. Disinfecting is not a substitute for cleaning. Disinfectants are only effective on clean surfaces. When preparing a previously occupied poultry house, follow these steps:

- Remove dust, dirt, crusted manure, litter, and feed.
- Clean buildings and all equipment thoroughly, including air intakes and fans.
- Disinfect. All surfaces must be dry before disinfecting. The building should be aired out before placing birds.

Environmental quality contributes to flock health. A poor environment makes birds more susceptible to diseases and facilitates the spread of diseases. An optimal environment provides shelter, protection, ventilation, temperature control, and comfort; convenient and adequate supplies of feed and clean water; and equipment and facilities arranged for both birds and personnel. If litter is used (say in a colony-type system), it should be absorbent, relatively dust-free, and resistant to matting. Litter under waterers and feed troughs should be replaced when it becomes damp or matted. Moisture in litter fosters growth of molds and bacteria. With cage systems, the operator must control the environment uniformly to get satisfactory performance.

Housing and Equipment

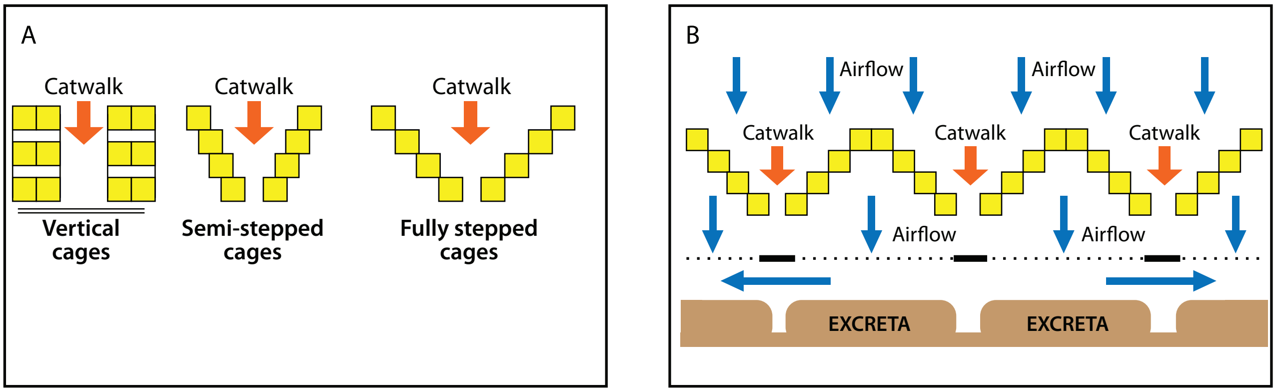
There are two major types of layer houses: (1) cage layer houses and (2) aviary houses and other litter/slatted floored systems. In evaluating each system, it is important to take into account bird comfort, operator efficiency, operational costs, egg handling, durability, and initial cost.

Cage Systems

Figures 18.10–18.14 show examples of conventional layer systems. The cage system is the major method of producing table eggs (see Figure 18.11 for various designs). The cage system involves many wire compartments each equipped with its own feeder and waterer and sloping floors so the eggs roll out of the cage for easy gathering by the egg belt (or by hand). Droppings fall through the cage floor into pits or onto dropping boards, where they are scraped into pits.

Many cages have been installed in a stair-stepped arrangement with three, four, and sometimes five rows of cages. There are service walks down each side of the house and between each row of cages. The advantages of a cage system compared to a floor system are that (1) there are more birds in a given size building, (2) it eliminates the need for pressure on the hens by breaking the flock up into many small societies, (3) it eliminates the floor-egg problem, (4) it produces an egg that is more acceptable to egg receivers and processors, (5) it reduces injuries to the hens, (6) it may

Figure 18.10 A frame multi-tier conventional cages for hens in layer houses open to the outside with a light proof screen that can be raised or lowered. (Courtesy of Big Dutchman)



A. Vertical, semi-stepped and fully stepped cages.

B. Layer cages above a droppings pit. The arrows show air flow.

Figure 18.11 Cage systems.

Figure 18.12 Conventional cages for hens in a layer house. (Courtesy of Big Dutchman)

reduce some diseases, and (7) the hens have been bred for this system.

Disadvantages of the cage system compared to a floor system are (1) the equipment costs more per bird than floor-system equipment, (2) hens tend to have a very rough and ragged appearance, (3) there may be behavioral problems (see below), (4) the entire house must have an acceptable total environment since the hens cannot move to a more comfortable location, (5) there may be more odor because the droppings are not mixed with litter and there is more dust from the hens because they are housed closer together, (6) the system is viewed negatively by activists and by members of the general public, and (7) there is pressure for large buyers of eggs for cage-free eggs with concomitant lower prices paid for eggs produced in caged systems.

According to the United Egg Producers, caging should allow hens to be able to stand upright, the birds should be treated with dignity, manure should not be able to drop on hens in lower tiers, clean water must be available at all times, the slope of the cage floor must not be above 8°, bird density should be 67 $inches^2$ (170 cm^2) per bird, and feeder space should be 1 inch (2.5 cm) per bird.

Behavioral Problems

With the caging of hens, abnormal behaviors are evident, including cannibalism and egg eating. Types of cannibalism that occur include:

- **Vent picking**: Picking of the vent, or the area below the vent.
- **Toe picking**: Toe picking is most commonly seen in chicks. It may be brought on by hunger.
- **Head picking**: Head picking may follow injuries to the comb.

Egg eating can be costly to producers. If one bird acquires the habit, it may spread quickly through the flock. Egg eating can lead to vent picking.

Environmental Enrichment

There is scope for enrichment in conventional cages with perches (see Figures 18.13 and 18.14).

Aviary Systems (Cage-Free Systems)

Among the aviary systems are (1) all-litter floor systems (with perches), (2) floor systems with areas of litter and other areas with slats and/or wire (with perches) (see Figure 18.15), and (3) multi-tier systems with litter floors together with slatted platforms (with or without perches). These can allow the birds out for some times of the day (see Figure 18.16). Litter areas provide a place for scratching; this reduces both feather pecking and even cannibalism.

Environmental Enrichment

Perches provide environmental enrichment (see Figure 18.17). With increasing bird density, there needs to be much greater perch length per bird, as seen below:

- 7 birds m^{-2} 1.2 inches (3 cm) per bird.
- 9 birds m^{-2} 3 inches (7 cm) per bird.
- 12 birds m^{-2} 5 inches (13 cm) per bird.

Figure 18.13 Conventional cages for hens viewed from above. This shows the space available per hen and the scope for enrichment with perches. (Courtesy of Big Dutchman)

Figure 18.14 Conventional cages enriched with perches. (Courtesy of Big Dutchman)

Figure 18.15 Aviary system showing floor and feeding troughs. (Courtesy of Big Dutchman)

Bird Density

The minimum hen density should be about 1.5 ft^2 (0.14 m^2) allowing birds to express normal behaviors.

Feeders

Troughs should be 3 inches (7.5 cm) per hen (see Figures 18.12 and 18.15). Round-pans should be 1.5 inches (3.8 cm) of perimeter per hen.

Waterers

- Bell drinkers: one per 100 hens.
- Nipple drinker or cup: one per 10 hens (see Figure 18.18).
- Water trough: 0.5 inches (1.3 cm) per hen.
- Waterers should be placed such that all birds are within 26 ft (8 m) of waterers.

Nests

Nests are used primarily for the production of hatching eggs, for cage-free production (see Figure 18.19), and by small-scale producers. Nests are important. They should be in spaces that are dark and free of drafts. Nests allow ease of egg collection, increased bird welfare by reducing cannibalism (pecking at the cloaca), and probably improved food safety. Eggs must be collected daily. Nest should be inspected and cleaned when necessary.

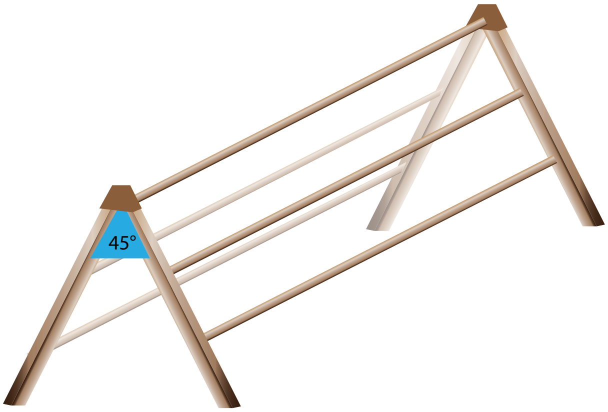
When pullets housed in aviary systems come into production, it is essential to encourage nesting by making frequent trips through the house. On each trip, pick up the floor eggs and place them in a nest. Level off the floor nests that birds have made in the litter. Persistence will pay off—pretty soon the pullets will get the idea.

Broodiness has been largely bred out of laying strains by selective breeding. It is rarely seen in hens in cages. Some broodiness may be occasionally observed in floor-managed flocks. Broodies (broody hens incubate/sit on eggs) should be removed as soon as observed and placed in a slat or wire-floored broody coop. Feed them a complete ration. They should be ready to return to the laying pen in about 7 days.

Heat Stress

Heat stress can first result in thin-shelled eggs. This is due to the reduction in the availability of car-

Figure 18.16 Alternative hybrid system with birds in (A) conventional cages for part of the day but (B) allowed out for the rest of the day. (Courtesy of Big Dutchman)



A. A-frame perches can be added to floor pullet or layer houses as enrichment. For maximal bird comfort, each perch should be 1 inch (2.5 cm) in diameter. Triangle indicates angle of 45°. (figure based on Hy-Line Red Book.)

B. Hens perched on perch. (Courtesy of Big Dutchman)

Figure 18.17 Perches are used to provide enrichment for hens in aviary/floor systems.

Figure 18.18 A hen drinking from a nipple drinker. (Courtesy of Big Dutchman)

bon dioxide/bicarbonate for shell mineralization. Moreover, there are acid-base issues (alkalosis) that can lead to mortalities. To redress this, potassium chloride, ammonium chloride, or sodium bicarbonate can be added to the water.

Producing Quality Eggs

Eggs are perishable and they should be handled as such. It is of utmost importance, therefore, that producers, packers, and retailers maintain superior quality. Consumers want eggs with fresh-laid appearance, good flavor, and high nutritive value. The shells should be strong, regular, and clean (see Figure 18.1 for how shell thickness can be determined); the white (or albumen) should be thick, clear, and firm; and the yolk should be light-colored.

Figure 18.19 Nests are important components of aviary/floor systems as seen in photos A and B. (Courtesy of Big Dutchman)

Textbox 18E

A Deeper Dive: Comparing Conventional and Aviary-Based Production Systems

Costs of conventional and aviary-based egg production are summarized in Textbox 18E Table 1.

1. Production parameters.
   The number of eggs produced was somewhat lower in aviary versus hens in conventional cages. The eggs produced as dozen (number) per bird being the following:
   - Conventional caged 30.2 (362.4)
   - Aviary 28.6 (343.2)
2. Welfare/health parameters.
   Cumulative mortality was markedly increased in the hens in an aviary as can be seen from the following:
   - Conventional caged 4.7%
   - Aviary 11.5%
3. Economics.
   Costs of pullet based on cost of rearing, etc.:
   - Conventional caged $4.48
   - Aviary $6.33

Textbox 18E Table 1 Comparison of different production systems per 100,000 birds.

Parameter	Conventional	Aviary (Cage-Free)
Building construction	$0.51 million	$2.45 million
Equipment	$1.00 million	$1.47 million
Total capital cost	$1.51 million	$3.92 million
Annual costs		
Interest and depreciation*	$75,726	$196,945
Pullets	$417,928	$632,872
Feed	$1,284,642	$1,247,537
Labor costs	$57,431	$211,738
Energy costs	$42,318	$42,919
Miscellaneous	$15,113	$14,307
Total	$1,893,158	$2,346,318
Production		
Eggs produced in million dozen	3.02	2.86

*Assumes 5% interest rate.

Calculated from Matthews and Sumner, 2015.

(Sources: Karcher et al., 2015; Matthews and Sumner, 2015).

Not all freshly laid eggs are high quality. However, a high percentage of top-quality eggs can be produced by adopting the following practices:

- Selecting birds with the genetic background to lay high-quality eggs.
- Feeding well-balanced rations with adequate calcium, phosphorus, manganese, and vitamin D_3.
- Keeping the flock disease-free.
- Replacing or recycling birds in the laying flock when they are about 70 weeks old—the highest-quality eggs are laid by recycled hens. Older hens (late in the cycle of producing eggs) lay eggs lacking in acceptable shell quality and albumen firmness.

Handling Eggs

Observing the following rules will aid in maintaining high-quality eggs all the way to the consumer:

- Gather eggs frequently or continuously using egg collection belts and convey to the egg processing room (see Figure 18.20).
- Produce clean eggs—eggs are usually cleanest when they are laid.
- Wash all eggs.
- Clean soiled eggs.
- Cool eggs properly. Cooling eggs immediately after gathering removes the animal heat and retards any reaction that might be conducive to deterioration of quality. The egg cooler should be large enough to accommodate the daily production plus eggs held until they are marketed. Eggs should be stored and moved to market keeping all eggs cool [< 45°F (7.2°C)] en route to market.
- Candle eggs to check for internal quality (see Figure 18.21). Candling is the most practical way to determine the interior quality of shell eggs. This allows identification and removal of defective eggs such as eggs with blood spots and checks (discussed in Section 18.9). The shell should be sound and free from checks or cracks and it should be of good texture.
- Separate eggs into weight classes (see Section 18.9).
- Pack eggs properly in cartons (see Figure 18.22). Eggs should be packed with small ends down. It is possible for the air cell to break loose and move to the small end when the large end of the egg is packed down. It is also important that cartons and cases be kept clean. This prevents the formation of mold that may pass off-flavors to the eggs.

Figure 18.20 Automated sorting of chicken eggs in a packing facility. (Source: zlikovec/Shutterstock)

Figure 18.21 A candled nonfertilized egg. (Source: Centers for Disease Control and Prevention)

Figure 18.22 Automated packaging of chicken eggs in an egg packing facility. (Source: zlikovec/Shutterstock)

Storing Eggs

Shell eggs (i.e., eggs for human consumption and sold in their shells) are a perishable product and should be handled with care. Since 1999, the USDA's FSIS requires shell eggs in the United States to be stored and transported refrigerated to below 45°F (7.2°C). An egg cooler room should have sufficient capacity to hold at least one week's production.

The requirements for **hatching eggs** differ. They are collected twice daily (more frequently during hot weather) and stored at 65°F (18°C). Increase the temperature to 75°F (24°C) 8–12 hours prior to setting eggs for incubation.

Molting

Molting is a normal process of birds, occurring in both sexes. In the wild state, birds shed and renew plumage, for instance, following migratory flights and/or following breeding. Chickens in commercial egg production have a different molting pattern. They have been bred for high egg production and their environment (light and temperature) is controlled to remove major seasonal influences. A natural molt does not normally occur until about 8 months of egg production when egg production is decreasing. Molting is under hormonal control.

By drastically reducing the length of light per day and/or reducing the intake of nutrients, molting can be induced (or speeded up) and egg production terminated. Egg producers molt hens by induced molting, also called induced resting, or recycling. Chickens are molted when egg production falls below 65% compared to peak rates of lay which are > 90% (see Figure 18.8). Egg production declines to this figure most typically at around 70 weeks of age or about 38 weeks of egg production. Molting can be induced by the following:

- Reduce day length to 6–8 hours of light per day.
- Feed intake/feed availability is decreased.
- Elevated temperature to reduce feed intake.
- The goal is to maintain body weight at 18 weeks (1.26–1.30 kg).
- During rest period there needs to be access to water.

Culling

With improvements in genetics, there is not a need to cull for poor production. However, culling is performed for injured or overtly unhealthy hens. The carcasses are either buried or composted.

Spent Hens

Spent hens have relatively little value and disposal is an issue as burial and composting may not be feasible. However, they can be ground and ultimately converted to poultry meat meal, poultry feather meal, or poultry bone meal. On-farm killing of spent hens must be humane. Among the effective methods includes modified atmosphere killing. This is a cost-effective method for killing before disposal.

18.8 Pullet Production

Pullets should have outstanding genetics and be healthy and vigorous. Proper feeding, care, and management during the pullet starting period develop the potential productive egg capacity of the birds, whereas poor practices and management may reduce the genetic potential.

Goals for Pullets

The following are goals for pullet (Hy-Line W-36) production.

- Body weight at 17 weeks old: 1.25 kg (2.8 lb).
- Feed consumed (kg): 5.25 kg (11.5 lb).
- Mortality between 1 day and 17 weeks: < 3%.

Management of Pullets

To assure satisfactory rearing record mortalities on a daily, weekly, and cumulative basis; determine body weight regularly (weekly) based on random selection of birds; record feed consumption on a daily, weekly, and cumulative basis; and record water consumption on a daily and weekly basis.

Down Time between Pullet Flocks

Phase 1

At least three weeks prior to the scheduled arrival of chicks (1) pullets are moved to layer houses; (2) litter, excreta, and feed are removed; (3) clean and disinfect; (4) ensure that the rodent control program is effective; and (5) ensure that all equipment is working (broken equipment must be repaired or replaced).

Phase 2

Five days before the scheduled arrival of chicks, fumigate the house and test for the presence of *Salmonella*. Two days before, clean and disinfect the water system and start the brooders (this is done one day before arrival in warm climates). One day before, place paper under the brooders and in the cages, set lights at 22–23 hours of light per day with an intensity of 30 lux (3 foot candles), ensure that the brooding house temperatures are correct, and fill the feeders.

Phase 3

On the day the chicks arrive, place the chicks (see Figure 18.23), fill the cup drinkers, add vitamins and electrolytes to the drinking water, and place the starter feed on paper in front of the feeders to encourage eating.

Figure 18.23 Brooding of day-old chicks (baby chicks) is critical to the success of pullet rearing. (Source: Keith Weller/USDA)

Biosecurity Essentials

It is critically important to follow biosecurity requirements for successful pullet production (see above for laying hens) (Section 18.7). For example, a strict sanitation program is essential when raising pullets. Other recommended rules include the following:

- Do not mix ages or strains of birds in the same house.
- Do not allow visitors in the house.
- Screen out birds and control rats, mice, and other rodents.
- Do not permit contaminated equipment to come on the farm.
- Use composting, an incinerator, or a disposal pit for dead birds.
- Keep birds free from external and internal parasites.
- Necropsy all dead birds.

Separating Male from Female Chicks

In white egg-laying strains, male chicks are distinguished from female by using the sex-linked rate of feathering locus. Male chicks (Kk) have slow feathering while female chicks (kk) show fast feathering. This is determined by inspection of the relative lengths of the primary wing feathers and primary wing feather coverts on newly hatched chicks. Alternatively, chicks can be sexed by inspection of the vent. Male chicks of laying strains are euthanized and the females are raised as replacement pullets.

Brooding of Replacement Pullets

Conditions for brooding replacement pullets include the following:

- Floor. It is desirable to have the same floor type for the grower house for the growing pullets and layer house for the hens. Paper is placed to cover floor slats or cage wire floor. This removed when birds reach 7–14 days old.
- Brooder. First week brooding temperatures should be at least 90–91°F (32–33°C) followed by reductions (see Table 18.10). Chilling or overheating young birds should be avoided.

- If on litter. Wood shavings, straw, rice hulls, or other commercial litter may be used. The litter selection should be on the basis of what is most convenient and economical.
- Feeders and waterers. It is important that adequate feeder and drinker space be provided (see Table 18.10).
- Supplementary feeders and waterers should be available during the brooding period. In addition, place feed on paper in front of feeders.

Table 18.10 Management of pullets.*

Issue	Requirement
Day length	
Days 1–7	20L:4D or 22L:2D or 4L:2D: 4L:2D: 4L:2D: 4L:2D
Week 1–9	11L:13D
Week 10–19	9L:15D or 10L:10D
Ambient temperatures	
Days 1–3	90–91°F (32–33°C)
Days 3–7	86–90°F (30–32°C)
Week 1–2	82–86°F (28–30°C)
Week 2–3	79–82°F (26–28°C)
Week 3–4	73–79°F (23–26°C)
Week 4–5	70–73°F (21–23°C)
Week 5–19	70°F (21°C)
Ventilation at ambient temperature of 70°F (21°C)	
Week 1	100 ft^3 per 1000 birds (170 m^3 per 1000 birds)
Week 3	150 ft^3 per 1000 birds (255 m^3 per 1000 birds)
Week 6	300 ft^3 per 1000 birds (510 m^3 per 1000 birds)
Week 12	750 ft^3 per 1000 birds (1275 m^3 per 1000 birds)
Week 18	1500 ft^3 per 1000 birds (2550 m^3 per 1000 birds)
Week 19	2750 ft^3 per 1000 birds (4500 m^3 per 1000 birds)
Stocking density	
Day 1–week 8	0.9 ft^2 $bird^{-1}$ (0.0835 m^2 $bird^{-1}$)
Week 8–17	1.3 ft^2 $bird^{-1}$ (0.1235 m^2 $bird^{-1}$)
Week 17–19	1.8 ft^2 $bird^{-1}$ (0.1635 m^2 $bird^{-1}$)
Feeders (feed availability)	
Trough/tube	5 cm $bird^{-1}$ (2 inches per bird)
Pan	One pan per 50 birds
Waterers (water availability)	
Cups	One per 15 birds
Nipple drinkers	One per 15 birds
Fountain-type	One per 150 birds

* It is recommended to follow the individual company's recommendations for different lines of pullets.

Based on Hy-Line International.

Rearing Recommendations

Table 18.10 summarizes general recommendations for rearing pullets including information on environmental factors (day length, temperature, and ventilation rates) and stocking density (stocking density per unit area, per feeders and waterers). Successful pullet rearing requires adequate floor space. Overcrowding may result in problems including increased mortality.

Lighting Programs for Pullets

The following are recommended:

- Photoperiod (see Table 18.10)
- 1–7 days use 20–22 hours of light per day (20L:4D or 22L:2D).
- Alternately for 0–7 days use 4L:2D: 4L:2D: 4L:2D: 4L:2D.
- 1–9 weeks step down photoperiod to 11L:13D.
- 10 weeks of age and onwards use 9L:15D or 10L:10D.

Light intensity:

- 0–7 days use 30–50 lux (3 to 5 foot-candles).
- > 7 days use 5–10 lx (0.5–1.0 FC) in cages or 15 lx (1.5 FC) on the floor.

Ventilation

It is important to have adequate ventilation for a number of reasons. It removes ammonia (NH_3) that is generated from the excreta. Ammonia has negative effects on both the birds and workers. Ventilation removes carbon dioxide (CO_2) from the growing pullets and bacterial degradation of excreta. It also removes water vapor (H_2O) from the growing pullets and any water spillage/leaks. Ventilation brings the relative humidity to the optimal level of 40–60%. There are negative effects of dry air on pullet health. Moreover, high relative humidity increases house microbial growth. It also helps to remove heat from the birds. As the ambient temperature rises, it is critical to increase the ventilation rate in an appropriate manner to assure bird comfort and health (see Table 18.11).

Table 18.11 Effect of ambient temperature on ventilation rate of pullets (6 weeks old).

Ambient Temperature	Requirement
90°F (32°C)	600 ft^3 per 1000 birds (1020 m^3 per 1000 birds)
70°F (21°C)	300 ft^3 per 1000 birds (510 m^3 per 1000 birds)
50°F (10°C)	200 ft^3 per 1000 birds (340 m^3 per 1000 birds)
32°F (0°C)	140 ft^3 per 1000 birds (230 m^3 per 1000 birds)
10°F (-12°C)	100 ft^3 per 1000 birds (170 m^3 per 1000 birds)
-10°F (-23°C)	100 ft^3 per 1000 birds (170 m^3 per 1000 birds)

Based on Hy-Line International.

Nutrition

Since the goal is to have low body weight in hens in order to limit basal metabolic rates in pullets, the dietary energy level of the ration is lower than that of broiler diets (see Table 18.12). Moreover, during the phases of growth and development of pullets, the levels of both energy and protein are decreased. The calcium level in the feed is increased prior to lay.

Pullet Health

There needs to be biosecurity (see above), a comprehensive vaccination program (see Table 18.13), and sanitation. A critical component to hen health is vaccination of the pullets (see Chapter 13).

Beak Conditioning

Beak trimming is the removing of a portion of the upper (and a lesser portion of the lower) beak of the fowl. It is an effective way to control cannibalism. This can be done at any time from a day old on. It is done with an electrically heated blade that both cuts and cauterizes to prevent bleeding. Chicks that have been beak trimmed do not need further attention for at least 1 year.

Dubbing

Dubbing is the removal of the comb from chicks. If done, dubbing is performed when chicks are a day old. At this age, there is little bleeding or discomfort. Dubbing reduces the possibility of injury to the large, tender comb surface and may allow birds with large combs to eat and drink more easily. A function of the comb is heat loss (by heat exchange). There are both real and perceived welfare issues. Dubbing may be stressful to the bird and has a significant labor cost. Hence, it should be done only if it serves a definite need, makes economic sense, and can be defended.

Aviary (Floor) Versus Cage Rearing of Pullets

There are differences in recommended environmental temperatures for brooding and early growth of pullets (see Table 18.14). Clearly, the recommended temperatures decrease as the chicks grow irrespective of pullet variety and whether birds are reared in cages or on the floor (as in an aviary rearing situation). However, perhaps unexpectedly and showing the value of research, there are differences in the recommended temperatures for birds reared in cages or on the floor and between white and brown varieties on floors but not in cages.

Enriched Environments

Enriched environments are used when pullets are raised on the floor rather than in cages. These can include perches, water platforms, or multi-tiered environments. These should be installed early so birds can acclimate.

Uniformity of Size

Uniformity of size for pullets is important. Lack of uniformity can reflect the stresses during growth

Table 18.12 Example of the feeds for pullets during growth and development.

Name	Time (Weeks)	ME* kcal/kg (MJ/kg)	Crude Protein (%)	Calcium (%)
Starter 1	0–3	3110 (13.0)	20	1.1
Starter 2	3–6	3085 (12.9)	18	1.1
Grower	6–12	3065 (12.85)	16	1.1
Developer	12–16	3065 (12.85)	15.5	1.1
Pre-lay	16–18	2955 (12.35)	17.5	2.75

*Metabolizable Energy using high of the Hy-Line range.

Table 18.13 Vaccination schedule of pullets.

Disease	Number of Vaccinations	Age (s) at Vaccination
Basic		
Marek's disease	1	Day old at the hatchery
Infectious bursal disease (IBD), also known as Gumburo	3	Weeks 2–5
Newcastle disease	2–4	Between day old to 16 weeks
Infectious bronchitis	2–3	Between day old to 11 weeks
Avian encephalomyelitis	1	Between 6 to 15 weeks
Fowlpox	2	Between day old to 12 weeks
Supplementary/optional		
Infectious coryza	2	6–10 weeks and 12–16 weeks
Fowl cholera	2	6 and 10 weeks or 12 and 16 weeks
Infectious laryngotracheitis	2	2–8 weeks and 9–14 weeks
Egg drop syndrome	1	14–16 weeks
Avian pneumovirus	1	4–9 weeks
Mycoplasma gallisepticum	1	9–14 weeks
Salmonella	2–3	Days 1–3; weeks 6–9 and weeks 14–16
E. coli	2	Weeks 0–6 and 12–14

Table 18.14 Recommended environmental temperatures for Hy-Line pullets.

Age	Cage White Varieties/Brown Varieties	Floor/Aviary White Varieties	Floor/Aviary Brown Varieties
1–3 days	88.0–89.6°F (30–32°C)	87.8–91.4°F (31–33°C)	91.4–95.0°F (33–35°C)
4–7 days	82.4–88.0°F (28–30°C)	84.2–87.8°F (29–31°C)	87.8–91.4°F (31–33°C)
Week 2	78.8–82.4°F (26–28°C)	80.6–84.2°F (27–29ºC)	84.2–87.8°F (29–31°C)
Week 3	73.4–78.8°F (23–26°C)	75.2–80.6°F (24–27oC)	78.8–80.6°F (26–27°C)
Week 4	69.8–73.4°F (21–23°C)	71.6–75.2°F (22–24°C)	73.4–77.0°F (23–25°C)
5 weeks old and older	69.8°F (21°C)	69.8°F (21°C)	

and development, including poor beak trimming, excessive or poor handling, limited water and/or feed availability, overcrowding around feeders and/or waterers, heat stress, diseases such as coccidiosis, and contamination of feeds with mycotoxins. The goal is 85% of birds being within 10% of the mean body weight. In comparison, a coefficient of variation of 10% has 68% birds within the mean (average) plus and minus the standard deviation.

Moving the Pullets—Catching, Transport, and Placement (in Cages or Aviaries)

Pullets are transferred from a rearing house to a layer house. This entails catching and transporting. It is important to do these in a manner that assures bird welfare by minimizing stresses (e.g., from loud noises, bird crowding, high or low temperatures, and by having a low light density), involves gentle handling, and minimizes any injury, such as bone breakage (this would lead to the bird being euthanized and hence a loss to the producer). All equipment used needs to be sanitized.

These goals in catching and transportation are met by having a well-trained catching crew and suitable supervision. One good approach is to lift individual birds by both hocks and then handling the birds upright. Birds should not be grabbed by a single leg or wing. Transportation requires clean (preferably steamed) coops and trucks.

Pullet Cost/Pullet Value

Pullet costs are based on the following:

- Feed consumed:
  13.9 lb (6.3 kg) $1.69 (variable but shown based on 2018)
- Chick $0.77
- Moving costs of pullet $0.16
- Other costs $1.24
- Total $3.86

Note: A pullet chick is worth more than a broiler chick.

Figure 18.24 USDA symbols for grade A and AA eggs. (Source: USDA)

18.9 Marketing and Processing of Eggs

Eggs are marketed either through processors (who may be the same company as the owners of the layer farm) who pick them up at the farm. They grade the eggs for size and quality and pay producers according to the quality and size (grading and sizing of eggs is discussed below). Large producers grade and package eggs on their establishments due to the lower costs involved. Shell eggs are stored and transported under refrigeration < 45°F or 7.2°C.

According to United Egg Producers, there is an increasing amount of eggs that are processed. In 2017, 59% eggs were sold retail, 30% were further processed, 8% were going to food service/restaurants, etc., and 2.9% were exported.

Inspection of Eggs—Quality of Eggs

USDA's Agricultural Marketing Service inspects eggs under the Egg Products Inspection Act of 1970. Eggs are classified into three grades: AA, A, and B (Figure 18.24), together with inedible and no grade.

Grade A and AA eggs are sold at grocery stores in the United States and used in some restaurants (see Table 18.15 and Figure 18.24). Grade B eggs are used in the food industry or for institutions. No grade eggs are contaminated with smoke or other agents that add a distinct flavor. See below for examples of inedible eggs. Table 18.15 summarizes the requirements for grade AA, A, and B eggs while Table 18.16 provides the minimum requirements for packages of eggs.

Inedible Eggs

According the USDA's AMS, inedible eggs include the following:

- Cooked eggs—proteins coagulated due to heating during collection, transportation, and processing.
- Musty eggs—have a musky odor.
- Moldy eggs (due to contamination for dirty water during washing).
- Large blood spots or bloody whites.
- Green whites, caused by *Pseudomonas* bacteria.

Table 18.15 USDA descriptions of egg types.

Quality	Whole Egg	Shell	Air Sac	White	Yolk
AA quality	"Practically free of defects"	Practically normal, unbroken	< 1/8 inch (< 3.175 mm)	Firm, Clear	Outline slightly defined. Practically free of defects.
A quality	"Practically free of defects"	Practically normal, unbroken	3/16 inch to 1/8 inch (3.175–4.76 mm)	Firm, Somewhat Clear	Outline fairly well defined. Practically free of defects.
B quality	Defects such as the developed spots	Abnormal, unbroken	> 3/16 inch (> 4.76 mm)	Weak and watery, small blood spots	Outline plainly visible. Enlarged and flattened. Clearly visible germ development.

Info from USDA's Agricultural Marketing Service.

- Mixed rots—the mixing of egg white and yolk due to breakage of vitelline membrane.
- Bloody rings and embryo eggs in fertilized eggs.
- Sour eggs, caused by *Pseudomonas* bacteria and fluoresce in UV light.

Table 18.16 USDA grading of eggs at destination.

Grade	Quality required	Tolerance permitted Percentage	Quality
At origin			
AA	87% or higher AA	Up to 13% Not over 5%	A or B Checks
A	87% A or better	Up to 13% Not over 5%	B Checks
B	90% B or better	Not over 10%	Checks
At destination			
AA	72% or higher AA	Up to 28% Not over 7%	A or B Checks
A	82% A or better	Up to 18% Not over 7%	B Checks
B	90% B or better	Not over 10%	Checks

Info from USDA's Agricultural Marketing Service.

Eggs Grading—USDA Definitions Related to Eggs

Appearance

- Practically Normal—normal shape, shell strength not affected by ridges and rough areas (AA or A).
- Abnormal—misshapen, ridges, thin spots (B quality).

Shell State

- Sound—shell unbroken.
- Check—shell cracked or broken but membranes are intact.
- Leaker—shell cracked and egg white leaking. These are "loss" (not used for human consumption).
- Clean—free from foreign substances and stains.
- Dirty—with foreign substances (dirt) and stains.

Egg Troubleshooting

The most common egg troubles and their causes are the following:

- **Weak shells**, which may be caused by disease, the age of bird, the strain of chickens, hot weather, lack of calcium in the feed, or deficiency of vitamin D.
- **Too many cracks**, which may be caused by weak shells, poor egg collecting (e.g., rough handling of eggs and container), or faulty washing of eggs and container.
- **Mottled shells**, which may be due to the eggs not being gathered often enough, the egg-holding room being too dry (below 75% relative humidity), or egg-packing material and cases that are too dry.
- **Weak whites**, which may result from eggs not being gathered often enough, eggs not being cooled quickly, eggs not stored at cool temperature and high humidity, eggs not packed daily as soon as cooled, egg-packing material that is too warm or too dry, disease, or the age of the birds.
- **Cooked whites**, which are generally caused by the egg wash water being too hot (use thermometer to check temperature) **or** eggs left in the water too long.
- **Yolk too colored**, due to the feed (yellow corn or green feed) or heat.

Appearance of Eggs

Eggs can exhibit unusual characteristics:

- **Blood spots**. These are due to the rupture of blood vessels with bleeding into the yolk at the time of ovulation. *No problem for consumption.*
- **Cloudy white**. This can be due to freshness. *No problem for consumption.*
- **Green ring**. This is due to overcooking. *No problem for consumption.*
- Pink or iridescent egg white: This is spoilage due to *Pseudomonas. Do not consume.*

Size of Eggs

The requirements for different sizes of eggs in the United States are summarized in Table 18.17. Peewee and small eggs are predominantly used to produce liquid eggs and in the food industry.

More Interesting Factoids about Eggs

Thousand-Year-Old Eggs?

These preserved eggs are popular in China and Southeast Asia. About 1.5 million tons of duck eggs are preserved annually in China. Chicken and quail eggs are also preserved. The eggs are treated with a mixture of strong alkali (such as sodium hydroxide or ashes), salt, black tea, and metal ions (such as copper) at room temperature. While not actually

1,000 years old, they can be between one month and up to several years old and are exempt from inspection by USDA's FSIS. Types of these eggs are Hulidan, Dsaudan, and Pidan.

What Are Pickled Eggs?

These are hard-boiled eggs pickled (preserved) in vinegar (dilute acetic acid) and spices.

Table 18.17 USDA definitions of egg size and weight classes.

Egg Size	Minimum Size of Eggs in Ounces (g)	Minimum Weight per Dozen in Ounces (g)
Peewee	1.25 (35.4)	15 (425)
Small	1.5 (42.5)	18 (510)
Medium	1.75 (49.6)	21 (595)
Large	2.00 (56.7)	24 (680)
Extra large	2.25 (63.8)	27 (765)
Jumbo	2.50 (70.9)	30 (850)

Info from USDA's Agricultural Marketing Service.

Liquid Eggs

The attraction of liquid eggs (with the shell removed) includes convenience, uniformity of product, and food safety, because liquid eggs in the US are all pasteurized. Liquid eggs have replaced shell eggs for many fast-food restaurants (for breakfast egg sandwiches) and many institutional users of eggs. Liquid eggs and other egg products now represent more than 30% of eggs produced in the United States. Liquid eggs are manufactured by breaking virtually all peewee and small eggs together with many medium eggs. In some cases, an egg breaker will use all the eggs produced on a single farm. Liquid eggs may be sold to a food manufacturer as liquid, frozen, or dried eggs. These may be further processed for retail products such as eggnog (see Figure 18.25), frozen French toast and waffles, ice cream, egg noodles, mayonnaise, baked goods, etc. (discussed in more detail in Section 18.8).

Figure 18.25 Eggnog with cinnamon is a popular drink for the holidays. In terms of food safety, this is much preferably made with pasteurized liquid eggs. (Source: Oksana Mizina/Shutterstock)

White and Brown Eggs

There is no difference in the nutritional value of white or brown-shelled eggs (see Figure 18.26). They simply come from different breeds of chickens. There are marked consumer preferences for the color of the eggshells. In the United States, the vast majority of eggs consumed have white shells. In New England and elsewhere in North America, there is still demand for brown-shelled eggs. There is a shift occurring where brown eggs are increasingly perceived as more "natural." Brown eggs are being used to market specialty eggs such as organic, cage-free, or high omega-3 polyunsaturated fatty acids (essential fatty acids) or vitamin E eggs. In Western Europe, consumers tend to prefer brown eggs.

Organic Eggs

There is increasing demand for organic eggs (see Table 18.6). According to *Business Insider*, the price for organic eggs in 2015 were much higher than conven-

Figure 18.26 White and brown eggs have the same nutritional value. (Source: Sakarin Sawasdinaka/ Shutterstock)

tional eggs with, for instance, large organic eggs being $4.79 per dozen compared to conventional eggs at $2.99 per dozen (Elkins, 2015).

Pasteurized Eggs

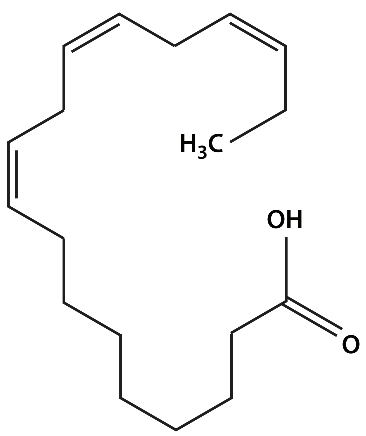
Pasteurized eggs greatly reduce the possibility of foodborne diseases from pathogens in the eggs. Some grocery stores in the United States now sell pasteurized eggs. There is a strong case for using pasteurized eggs in foods that are not cooked (such as homemade mayonnaise) and/or are to be used for people with a compromised immune system.

TEXTBOX 18F

A Deeper Dive: Omega-3 Eggs

Omega-3 fatty acids are important nutrients for people. Egg levels of the polyunsaturated fatty acid (PUFA) alpha-linolenic acid (ALA) is increased by feeding flax oil. Such nutritionally enhanced eggs are sold in the United States. ALA can be metabolized to other omega-3 fatty acids—eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). These are the important fatty acids in fish oils.

Egg levels of another polyunsaturated fatty acid (PUFA), docosahexaenoic acid (DHA), can be markedly increased if the feed contains microalgae. The DHA is stable when the feed is pelleted containing the microalgae but not if added as oil. This source of omega-3-fatty acids has been approved by the European Union and its use in the United States is possible with a novel food application to the FDA underway. PUFA are susceptible to peroxidation.



Textbox 18F Figure 1 Structure of the omega-3 fatty acid, alpha-linolenic acid (ALA).

Eggs with Elevated Levels of Specific Nutrients (Supplementation)

Egg companies market eggs based on increased contents of lutein or omega-3 and omega-6 fatty acids or vitamins D and E together with both lower calories and saturated fatty acids. They further claim that this is based on the feed the hens receive, such as the inclusion of canola oil, rice bran, alfalfa, sea kelp, and vitamin E. The ability to increase the amounts of fat-soluble nutrients into eggs by supplementing the hen's feed is well supported by research.

18.10 Uses of Eggs in Foods and the Food Industry

Eggs and Foods

Eggs and/or egg yolks are used extensively in the food industry, such as in pastries, cakes, muffins, ice cream, soups, mayonnaise, and pasta. Egg yolks and eggs are used as emulsifiers in the production of mayonnaise, sauces, etc., and as binding agents in cakes and pastries. Egg whites are used in meringues, mousses, cakes, etc., due to their capacity to form stable foams.

Lysozyme and Food Safety

The egg white protein lysozyme has strong antimicrobial properties. Following purification from egg whites, it is used as a natural preservative preventing spoilage in cheese, fish, poultry, Chinese noodles, sushi, and other foods. It is also effective in suppressing/inhibiting foodborne pathogens in toxin production from, for instance, *Clostridium*. It is used in the production of some wines by inhibiting lactic acid bacteria. To avoid having to name lysozyme as an ingredient, the lysozyme is bound to insoluble supports that can be easily separated from the wine. In addition, lysozyme is used in biomedical research.

18.11 Biomedical Egg Products

There are multiple biomedical uses for eggs or their constituents.

Avidin

The egg white protein, avidin, binds biotin. This property is used in biomedical research; being the basis for the ABC (avidin biotin complex) assays. Highly purified avidin can be used with proteins that have been labeled with biotin. These proteins include enzymes, such as horse radish peroxidase, and antibodies. The biotin labeled proteins are used in western blot assays and enzyme-linked immunosorbent assay.

Fertilized Eggs

Embryonated or fertilized eggs are supplied to schools and colleges for uses in instructional laboratory classes. In addition, they are used in biomedical research (see Figure 18.27).

Specific-Pathogen-Free (SPF) Eggs

Specific-pathogen-free (SPF) eggs are used in vaccine production. The eggs are verified by testing free of 30 specific pathogens such as *Salmonella* species *mycoplasma gallisepticum*, infectious bronchitis, and Newcastle disease. They need to meet specific requirements of the USDA in the United States and European Pharmacopoeia (PhEur) in the European Union. SPF eggs come from SPF leghorn-type hens held under rigorous conditions. These conditions include HEPA-filtered air, positive air pressure (such that air flow is from inside to outside), stringent biosecurity, and the SPF flocks being located in geographical areas with few poultry. The parent hens of the SPF hens are vaccinated against the 30 pathogen series.

SPF Chick Embryo Products

A series of important cell types for biomedical sciences are produced from SPF chicken embryos, including dermal cells, fibroblasts, kidney cells, and liver cells.

Hyperimmune Eggs

Eggs can be a source of passive immunity to people and animals. Moreover, if the hen is immunized against foodborne pathogens, the egg will have high concentrations of antibodies against the pathogen (in these hyperimmune eggs).

What Is Passive Immunity?

Passive immunity is the receiving of antibodies from another individual. In poultry and other birds, antibodies from the hen are transferred to the developing embryo and these remain to provide immunity to the growing chick (in **natural passive immunity**). This is similar to the transfer of antibodies to the developing human fetus from the mother to give the neonate immunity. In addition, mother's milk and particularly the first milk, colostrum, provides antibodies to the intestine of the newborn. Uncooked eggs contain chicken antibodies that could have effects in the human intestine (in **artificial passive immunity**). Other forms of immunity are **active immunity** where an animal or person produces antibodies (or another immune response) to pathogens (in **natural** active immunity) or vaccines (in **artificial** active immunity).

18.12 Industrial Uses of Eggs

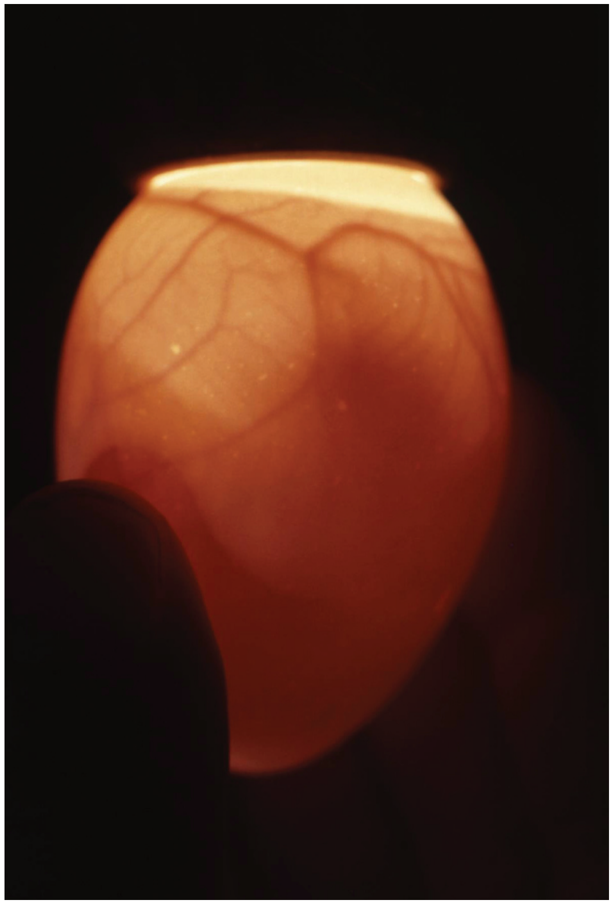
There are nonfood uses of egg whites such as in cosmetics, paints, glues, and in tanning leather. This is due to their binding properties. Moreover, egg yolks have nonfood industrial uses such as in cosmetics, glues, and paints due to their emulsifier effect.

Textbox 18G

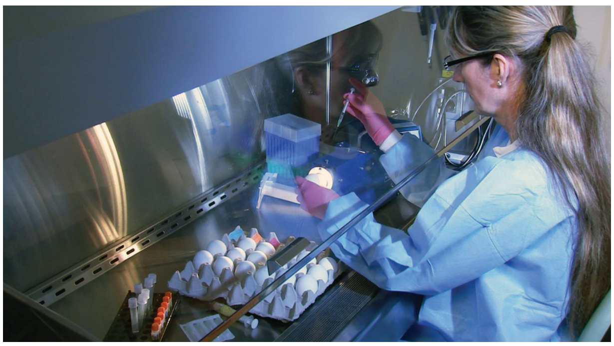
A Deeper Dive: Hyperimmune Eggs

Hyperimmune eggs provide passive immunity within the intestines to the animals and people who consume the eggs or purified yolk products (Marcq et al., 2010). For example, hens can be immunized against rotavirus (Rahman et al., 2013; Thu et al., 2017); rotavirus being a common cause of diarrhea in people. Similarly, hens can be immunized against Shiga toxins (Stx1 and Stx2) and produce IgY and these are found in the eggs (Neri et al., 2011). Shiga toxins are responsible for the severe consequences of enterohemorrhagic *Escherichia coli*. Presently chicken IgY is used in livestock, such as pigs, and people. They are marketed as supporting immune status and as natural.

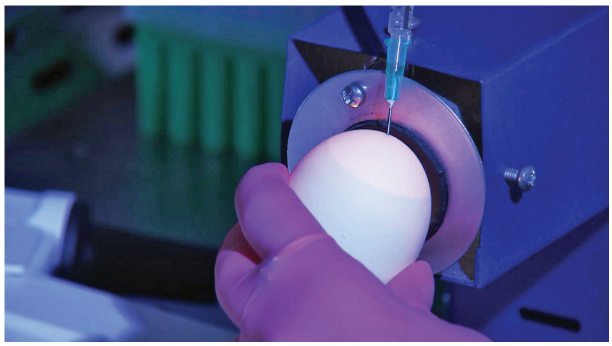
A. To ensure the the egg is embryonated, it is candled.



B. An embryonated egg with blood vessels easily seen.



C. An embryonated egg being injected in a Centers for Disease Control and Prevention (CDC) laboratory to create egg-based flu vaccines.



D. Close up of injection.

Figure 18.27 Fertilized or embryonated chicken eggs are used in biomedical research. (Source: CDC)

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19

Broiler Chickens and Chicken Meat

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List the major weights and ages at which broilers are marketed.
2. List the basic composition of broiler meat.
3. List the major breeders of commercial broilers.
4. Give recommendations on brooding, rearing, and production of broilers.
5. List the major diseases encountered in broiler production and give recommendations for prevention or control.
6. Give reasons why several programs of lighting can be used to increase growth of broilers.
7. List the top broiler-processing companies in the United States.
8. List the typical procedures performed in the conversion of broilers to meat.
9. Know the requirements for broiler production (e.g., temperature, ventilation, etc.).
10. Know how spent litter is used.
11. Know how mortalities are disposed of.
12. Know the roles a picker, scalder, and other components of broiler chicken processing.
13. List the by-products of poultry processing.
14. Know the proportion of chicken sold as whole birds, breasts + thighs + legs + wings and further processed.
15. List the goals of broiler breeders.
16. Define photostimulation.
17. Know the relationship of photostimulation and broiler breeders.

19.1 INTRODUCTION

The production of chicken meat is of great importance worldwide and is growing due to its price, perception of healthiness, versatility for cooking, and its ready availability as staples at popular restaurants (see Figure 19.1).

In 2018, the National Chicken Council estimated the impact of the chicken industry in the United States to be the following:

- 30,000 family farms (growers and producers of hatching eggs).
- 180 Processing plants.
- 280,000 workers directly employed.
- 1.3 million workers indirectly employed.
- US $65 billion of product (wholesale value).

In 2017, the United States consumed more chicken than anywhere else in the world, averaging about 92 pounds (42 kg) per person.

Figure 19.1 Consumption of chicken is increasing globally because of growing consumer demand and low cost. The ultimate purpose of raising broiler chickens is to produce chicken meat for the growing human population. Some common ways of serving chicken include (A) roast chicken and (B) buffalo wings, which are popular appetizers in restaurants and at home, particularly on Super Bowl Sunday in the United States. (Sources: MaraZe/Shutterstock [A]; Brent Hofacker/Shutterstock [B].)

19.2 Composition of Chicken Meat

The carcass of poultry consists of muscle, adipose tissue (fat), and bone. A major advantage of chicken meat, particularly breast, is the low fat content. Uncooked chicken breast is composed of 69% water, 20% protein, and 11% fat. With removal of the skin, the fat content is decreased to less than 2%. Uncooked chicken dark meat is composed of 65% water, 17% protein, and 18% fat. Removal of the skin reduces the fat to 4%. Not only does skinless chicken have a much lower fat content than red meat but, in addition, there is proportionately less saturated fatty acids. Chicken fat has a profile of fatty acids with less stearic (a saturated fatty acid) and more unsaturated fatty acids (e.g., linoleic) than beef or pork. Because saturated fatty acids are associated with elevated arterial cholesterol and cardiovascular disease, skinless poultry meat has this double advantage as long as it is not cooked with animal fat (e.g., butter).

Textbox 19A

A Deeper Dive: Muscle

Protein makes up about 19% of chicken meat. There are multiple proteins, including the following:

- **Myofibril proteins,** which cause muscle contraction (they represent 61% of muscle protein and include actin, myosin, and tropomyosin).
- **Sarcoplasmic soluble proteins,** such as myoglobin and the glycolytic enzymes (representing 29% of muscle protein).
- **Stromal proteins,** including collagen (found in connective tissue) and mitochondria (representing 10% of muscle protein).

Skeletal muscle myofibril proteins are arranged parallel to each other in myofibrils (see Chapter 4 for details). Proteins represent about 19% of the chemical composition of muscle:

- **Myofibril proteins** (11.5%), including 5.5% myosin, 2.5% actin, 0.6% tropomyosin, and 0.6% troponin.
- **Sarcoplasmic proteins** (5.5%), including 0.2% myosin, 0.6% hemoglobin, and 2.2% glycolytic enzymes.
- **Stromal proteins** (2.0%), including 1.0% collagen and 0.95% mitochondria.

Myoglobin (a protein with a heme unit that temporarily binds oxygen) concentrations are much higher in dark meat than red meat. There are changes in the meat after slaughter. These include pH and rigor mortis (stiffness of death due to muscle contraction as glycogen is depleted). The pH in meat declines after death. Components of the criteria for the quality of meat include the pH and the rate at which pH declines.

Adipose Tissue

There are two major sites for adipose tissue in poultry: subcutaneous (under the skin) and abdominal, or leaf fat (this is the body cavity and mostly removed during evisceration). Most adipose tissue is of one cell type—the adipocyte, or fat cell. This is a large cell with a droplet of fat making up most of the cell. In turn, the vast majority of the fat stored in the fat cell is triglyceride—molecules containing three fatty acids combined with glycerol.

19.3 The Biology of Meat Production

The rapid growth rate of broiler chickens reflects superior genetics (intense selection for growth rate) and improved nutrition. The effects are manifest by nutrient availability to growing tissues and endogenous hormones and factors. In chickens, as in other livestock, growth arid development is controlled by numerous hormones and growth factors.

Hormones and Growth

Growth of muscle and bone requires normal levels of the hormones produced naturally by the chicken, including thyroxine (T_4) and its active metabolite, triiodothyronine (T_3); insulin-like growth factor-1 (IGF-1); and growth hormone (GH) (or somatotropin).

Myths about Chicken

Myth: Broiler chickens are big because they are injected with hormones (or receive them in their feed).

This is not the case. The large size of today's chickens is due to improved genetics, nutrition, veterinary care, and overall husbandry. The use of hormones in poultry production is not legal in the United States or anywhere else. Hormones just don't work to increase growth in poultry! For instance, anabolic androgens inhibit growth. Other hormones either have no effect on growth, or even inhibit it.

Muscle Development

Skeletal muscle is the major component of meat, thus muscle development and growth is the basis of meat production. Muscles develop in the chick embryo. The cells that are to become muscle are called **myoblasts**. In the early embryonic stage, the myoblasts divide repeatedly, forming many of these cells. These myoblasts then come together to form **myotubes.** The cell membranes break down, creating a myotube with multiple nuclei and a common cytoplasm. The muscle proteins are synthesized in the myotube by ribosomes. The major muscle proteins are actin and myosin.

Muscle Growth

Muscle growth includes increases in the size of muscle fibers due to accumulation of specific proteins and the incorporation of nuclei from **satellite cells.** Surprisingly, muscle protein is being both synthesized and broken down (or degraded) during growth. The rate of accumulation or accretion of muscle protein is the difference between the rate of synthesis and the rate of degradation.

$$\text{Rate of muscle protein accretion} = \text{Rate of muscle protein synthesis} - \text{Rate of muscle protein degradation}$$

Adipose Tissue

The adipose tissue stores fat as triglyceride. Unlike the situation in many mammals, in poultry the liver produces the fatty acids. These travel to the fat cells (adipocytes or adipose cells) via the bloodstream linked to transporter proteins—lipoproteins. In the adipocytes, the fatty acids are linked (esterified) to glycerol to form triglyceride. At times when energy is needed, the triglyceride can be broken down in the process of lipolysis. Hormones change the rates of fatty acid synthesis and lipolysis. For instance, glucagon (released at times when food is not available) acts to inhibit fatty acid synthesis and increase triglyceride breakdown.

Impact of Adipose Tissue on the Poultry Industry

Adipose tissue, and particularly excess fat, has negative consequences for the poultry industry. Fat is high in calories and energy dense, and therefore takes a considerable amount of feed (lowering feed: gain efficiency). Abdominal fat is removed from the carcass as a waste and converted by rendering to a by-product. Excess fat is not a desirable trait for the consumer. While subcutaneous fat adds to the eating quality of chicken, it also has disadvantages for people concerned with their weight (due to the calories) or cardiovascular disease (saturated/animal fat content).

TEXTBOX 19B

A Deeper Dive: Lipid/Fat Metabolism and Adipose Tissue Development

Lipogenesis, or Fatty Acid Synthesis

In chickens and other poultry, fatty acids are synthesized in the liver. They are then transported to adipose tissue via the bloodstream. Fatty acids are stored as triglyceride. Synthesis of fatty acids occurs when energy supply is greater than demand.

Glucose → Liver → Fatty Acids →
Adipose Cell → Triglyceride

Triglyceride Synthesis by Adipose Tissue

Triglycerides are synthesized in the adipocytes from fatty acids and **glycerol-3-phosphate**, in a ratio of 3:1. The glycerol-3-phosphate is derived from glucose by the process of glycolysis. Triglyceride synthesis occurs when energy supply is greater than demand.

3 Fatty Acids + Glycerol-3-phosphate → Triglyceride
↑
Glucose

Triglyceride Breakdown by Adipose Tissue

Triglyceride breakdown, or **lipolysis**, is the enzymatic cleavage of triglyceride to yield fatty acids and glycerol. Lipolysis occurs when energy supply is less than demand.

Triglyceride → Hormone sensitive lipase →
3 Fatty Acids + Glycerol

Adipose Tissue Growth

The amount of fat or adipose tissue increases during growth by both increases in the number of fat cells and an increase in the size of adipocytes due to triglyceride accumulation. The number of adipocytes depends on the rate of differentiation or adipogenesis of preadipocytes, and the number of preadipocytes.

As growth progresses, the relative importance of increasing the fat cell size becomes progressively greater (see Textbox 19B Figure 1). Some breeds of poultry have more fat cells (see Textbox 19B Figure 2). Females have more fat cells and larger fat cells than males. The size of the fat cells is also affected by the nutrition the bird is receiving.

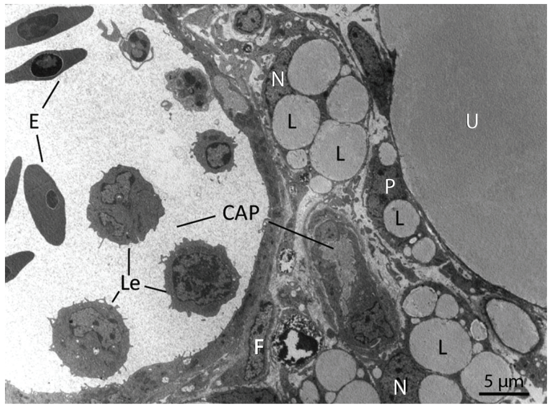
Proliferation of the precursor cells for chicken adipocytes stimulated by the growth factors include the following (Butterwith and Goddard, 1991):

- Transforming growth factor-alpha (TGF-α) ↑
- TGF-β ↑
- Platelet-derived growth factor (PDGF) ↑
- IGF-1 potentiation of TGF-α and PDGF effects

Adipocyte differentiation or adipogenesis influenced by the neuropeptides, hormones, and growth factors include the following:

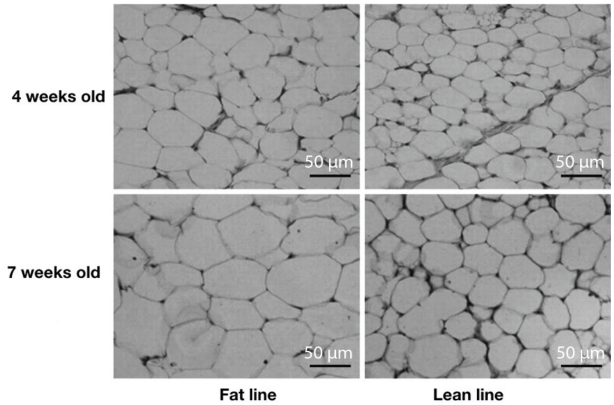
- Neuropeptide Y (NPY) ↑
- Adiponectin (adipocyte hormone) ↓
- Transforming growth factor-β (TGF-β) ↓

Peroxisome proliferator-activated receptor gamma (PPARγ) has an important role in adipocyte differentiation (Wang et al., 2007).



CAP capillary lumens
N nuclei
L lipid droplets
U unilocular adipocytes
P pericytes (probably an earlier stage of preadipocyte development)
F fibroblasts
E erythrocyte
Le leukocytes

Textbox 19B Figure 1 Electron micrograph of abdominal fat pad tissue from a 7-day-old chicken. (Source: Guo et al., 2011. Reproduced with permission from Oxford University Press.)



Textbox 19B Figure 2 Increasing size of adipocytes between 4- and 7-weeks-old in fat and lean lines of chickens. [Bar = 50 µm] (Source: Guo et al., 2011. Reproduced with permission from Oxford University Press.)

19.4 An Overview of Commercial Production of Broiler Chickens

The increase in the production of broiler chickens is attributed to genetics/breeding; nutrition; disease control; management, including vertical integration or vertical coordination in the supply chain; efficient processing, further processing, and marketing; and consumer demand for high quality tasty protein.

Broiler production has changed in the United States from small, independent farm flocks and small processors scattered across the country to a highly integrated, efficient industry that is concentrated in fewer areas. Table 19.1 lists the largest broiler processors in the US. A similar situation exists throughout North and South America, Europe, Asia, and is beginning in Africa. According to WattAgNet, the largest global poultry (chicken) producers in 2018 are (1) JBS (Brazil); (2) Tyson (Unites States); (3) BRF (Brazil); (4) Wen's Food (Peoples Republic of China); and (5) New Hope (Peoples Republic of China).

Poultry Production in the European Union

About 18.5% of farms in the European Union produce broiler chickens. However, large-scale production predominates for the amount of poultry meat produced. Poultry production in the European Union can be categorized as the following:

- Farms with less than 5000 broiler chickens produced 6.5% of total production.
- Farms with more than 5000 broilers chickens produced 93.5% of total production.
- Farms with less than 5000 broilers chickens represent over 99% of European farms producing broilers.
- Farms with more than 5000 broiler chickens represent less than 1% of European farms producing broilers.

Table 19.1 Top five chicken producers in the US in 2017.

Company/Rank	Production Million lb per Week (Billion lb per Year)[a]	Production Million Metric Tons per Year[a]	Revenue in Billion US$
1. Tyson Farms	174.80 (9.8)	4.14	11.4
2. Pilgrim's Pride Corp.	154.2 (8.1)	3.34	8.8
3. Sanderson Farms, Inc.	66.2 (3.44)	1.56	3.34
4. Perdue Foods	61.74 (3.21)	1.46	3.9
5. Koch Foods	48.0 (2.50)	1.13	3.3

[a] Ready-to-cook chicken (RTC) weight.

Info from WattAgNet.

Business Aspects

Broiler chicken production is both labor intensive and capital intensive. The overall structure of broiler chicken production is that they are two types of participants or players: integrators and growers. A typical broiler unit within an integrator consists of a hatchery, a feed mill, a processing plant, a field service and management staff, and 150 to 300 growers. With the increase in size and integration of broiler enterprises, the business aspects have become more important (this is discussed in more detail in Chapter 21).

Processing Companies or Integrators

Integrators (processing companies) usually own the hatcheries, feed mills, processing plant, and the chickens throughout the growing process. Integrators incubate eggs, transport chicks to growers, harvest chickens by company-employed catchers, transport the birds to the processing plant, process (slaughter and dress) the birds, and then further process. The processing company provides feed to the growers. The integrator employs nutritionists to assure that broiler chickens receive feed for optimal performance based on the lowest priced feed ingredients, veterinarians for bird health, service technicians, catchers, processing plant staff, and management. The integrator may also own the primary breeding company.

Primary Breeders

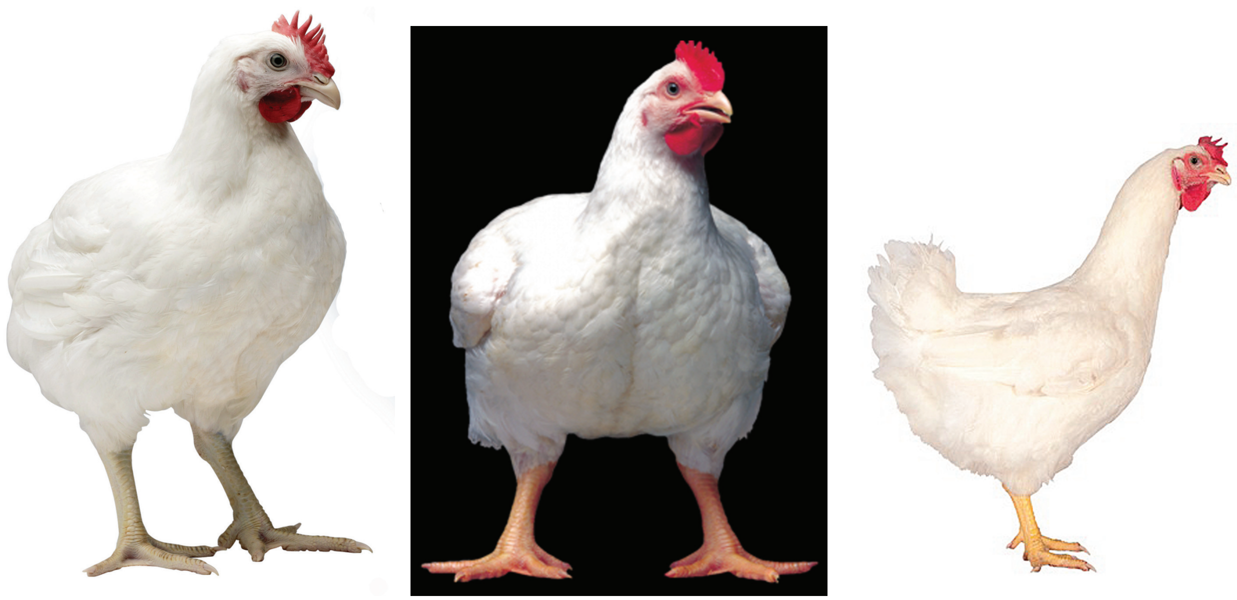
- **Aviagen.** The broiler breeding brands of Aviagen Group include Arbor Acres, Hubbard, Indian River, Ross, and the Rowan Range portfolio of brands (including Rowan 708, Ranger Premium, Ranger Classic, and Rowen Ranger). Aviagen has its headquarters in Huntsville, Alabama, in the US. Aviagen is part of the EW Group GmbH; a holding company based in Visbek, Niedersachsen (Lower Saxony), Germany.
- **Cobb-Vantress.** Owned by Tyson Foods and headquartered in Siloam Springs, Arkansas.

Growers

Growers are independent farmers who raise broiler chickens in their own facilities (see Figure 19.3A). The growers are responsible for the care of the chickens, biosecurity, sanitation, maintenance of the buildings and equipment, provision of new litter, disposal of cake (caked litter) and spent litter, disposal of mortalities, and meeting requirements of the contract. Service technicians (previously called field men or field personnel) are employees of the integrators and visit the growers on a regular basis.

Critical Responsibilities of Growers

- **Biosecurity**. Assuring the adherence to a written biosecurity plan.
- **Sanitation**. Between flocks, broiler houses must be thoroughly washed and disinfected. It is very useful to have hoses that can be moved through 360°. If litter is being re-used after the flock has been removed, switch off ventilation. Litter temperatures are allowed to rise due to microbial action on the excreta (fermentation). This reduces pathogens. There is also a buildup of ammonia that will be dissipated when the ventilation is resumed prior to preparation of the house for the next flock.
- **Care for birds**. Daily walk-throughs of the entire facility (all houses) looking for and recording mortali-



Cobb 500 Ross 308 Hubbard Classic

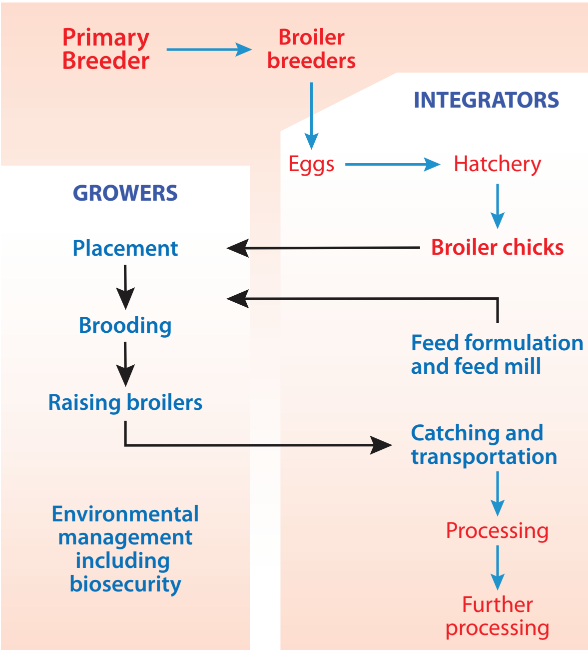
Figure 19.2 Examples of broiler chickens from different breeders.

ties and any other unusual situations; unusual bird behavior, such as crowding; height of feeders and waterers such that all birds can get sufficient feed.

- **Equipment**. Running normally with adequate ventilation and temperatures maintained within the desired range.
- **Utilities and gas**. To heat, ventilate, and cool poultry houses.
- **Quality water for the birds**. Chlorinated city water is present on 70% of grower operations. For others, it is important to assure quality water from wells or other sources. Biofilm builds up in water lines. This needs to be removed by flushing with high pressure water.

Financing

Banks and the Farm Credit Association finance the broiler industry through credit to growers with mortgages and the contract with integrators as collateral. Moreover, banks extend credit to integrators (for feed manufacturer, processing plants, and hatcheries). Large integrators also have access to the bond market for money.



A. Operations involved in producing broiler chickens.

B. Broiler chicks being brooded.

C. Growing broiler chickens in a poultry house.

Figure 19.3 Broiler chickens.

Corporate Structure of Integrators

Some integrators, such as Tyson and Pilgrim's Pride, are public companies (traded on the stock market and held to strict financial reporting requirements). Others such as Perdue Farms are privately held.

Labor Requirements

Labor is an important factor in the profitability of a grower. The more broilers raised per person, the lower the production costs and the bigger the operation can grow. The labor requirements for growers are discussed in more detail in Chapter 21. It is important for the grower to be thinking in terms of paying themselves for their own time put in.

Cost of Producing Chicken Meat

The cost of producing chicken meat has declined steadily over the last 50 years.

Records to Kept by the Grower

Good management requires data on the performance of each flock. Good records are exceedingly important. Three types of broiler records should be kept: (1) those related to the flock (such as mortality, water usage by the birds, bird behavior, ability of birds to eat or drink, etc.); (2) those related to the maintenance of the buildings and equipment; and (3) those related to profit or loss. Costs and returns in the broiler business are critical to decision-making when deciding whether or not to enter, expand, or sell the business; in determining how well an established enterprise is doing; and in reporting income for tax purposes. Even with the same production contract, costs and returns of broiler production may differ from year to year and from area to area.

Returns to Grower

Annual net returns to contract poultry producers are modest ($3,000–$5,000 for each house), at least until the unit is paid for. Labor requirements are high if the labor of the grower is included (see Chapter 21 for details). Similarly, the capital requirements are great. Returns from contract broiler production are consistent and dependable, making this attractive to many farm families. Moreover, income can be supplemented by part-time or full-time off-farm employment.

As in any business, profits in broiler production can be increased by lowering costs and increasing returns. Net returns depend on the contract, any performance payments, efficiency of production, lack of mortality, quality of husbandry, sale of used litter, and aggregate live weight produced. Broiler growers should follow production goals required in the contract with the integrator. For instance, such a contract may require birds to weigh 5.0 lb (2.3 kg) at 6 weeks of age, a feed conversion of 1:1.85, and mortality under 3.0%.

The Good vs. the Average Grower

The **good grower** controls the environment for their birds and gets consistent good performance. The **average grower** may get lucky with the performance of their birds but this is not going to be consistent.

19.5 Overall Considerations of Broiler Chicken Management

Overall broiler production is summarized in Figure 19.3. Broiler chicks are transported to the grower's poultry facility and are brooded and then grown to the required weight or age (Figure 19.3).

Lowering Costs

Because most commercial growers raise broilers in large volume, small differences in production costs have a great impact on profit. **Feed** is the highest production cost item and any change in feed cost and feed efficiency will cut the cost of production (to the benefit of the integrator). This can lead to increased payments to growers.

Mortality decreases total live weight produced (on which payment to the grower is based) and also increases feed consumption per unit of broiler produced.

Building and equipment costs are high, particularly with specific requirements from the integrator. Also, growers should visit successful growers, expositions, and so forth, to learn what is new and working well.

Increasing Returns

Contract payments vary. Growers increase their returns by producing market birds with greater live weights, having lower mortalities, improving feed to gain ratios, increasing flock uniformity based on coefficient of variation and target band, and selling the coproduct—spent litter.

What Is the Coefficient of Variation and What Is Its Impact?

Coefficient of Variation (CV) is a measure of how uniform a population is and is presented as a percentage. It is calculated from the standard deviation (SD) times 100 divided by the mean or average. For instance, if the mean body weight is 1.0 kg and the SD is 0.10 kg:

$$CV = \frac{0.10 \times 100}{1.0} = 10\%$$

A goal of broiler production is flock uniformity at harvesting or a low CV of body weight.

Impact

As the CV increases, there are more and more chickens that do not meet the targeted band width. For example, with a band width 3.7–4.6 lb (1.7–2.1 kg), how does CV influence the percentage of birds that meet the targeted band width?

- CV 8% = 86% of birds meeting the targeted band (14% of birds *not* meeting band).
- CV 10% = 76% of birds meeting the targeted band (24% of birds *not* meeting band)
- CV 12% = 67% of birds meeting the targeted band (33% of birds *not* meeting band)

Separate rearing of males and females reduces CV.

Housing and Equipment

Poultry houses are considered by the USDA as single-purpose agricultural structures. In commercial broiler production, chicks are transported from the hatchery to the poultry house and then spend the rest of their lives in the house. Thus, brooder houses are cleaned and disinfected between flocks. Broiler houses and equipment are to provide for bird comfort and assure good performance (also see Chapter 17).

Broiler Flock Management

Broiler production follows an "all-in, all-out" system with chicks being brought into a clean house. The birds are grown to market weight. Following the harvesting of the birds there is at least one week down to clean, disinfect, remove litter (if the litter is being removed), and prepare for the next batch of chicks. The down time is increased to about two weeks in antibiotic-free systems.

Housing

The broiler house should provide clean, dry, comfortable surroundings throughout the year. It should be kept warm but not too warm and the litter should be kept dry. There must be ventilation with fresh air circulated, but the house should be free from drafts.

Location

The broiler house should be located to comply with state regulations concerning the required separation distance to neighbors' residences (complying with the law is a good-neighbor policy) together with the distance to other poultry units (~1 mile or 1.6 km) for biosecurity. Planting rapidly growing trees around the unit reduces neighbor complaints ("out of sight, out of mind"). The trees can also influence local wind patterns, air currents, and air or odor from houses being diluted further and moved to higher altitudes.

There should be adequate water drainage, but broiler houses should be set back a reasonable distance from streams, creeks, rivers, and lakes to prevent polluting surface water. There needs to be a good access road from the houses to the highway because of feed and bird hauling. The poultry unit should be set back from roads used to transport birds for biosecurity. The cost of bringing in utilities such as water, gas, and electricity should be considered.

Construction

Broiler houses in different areas are of many types and dimensions, e.g., 43 × 500 ft (13.1 × 152 m), 50 × 600 ft (15.2 × 183 m), and 60 × 600 ft (18.3 × 183 m). They are constructed of various materials. Poultry houses should be economical, yet substantial enough to last more than 15 or 20 years (the term of the loan from the bank) with a minimum of maintenance. The house should be sufficiently insulated to heat easily in winter and have sufficient ventilation for cooling birds in the summer.

Most broiler houses have concrete floors, which is advantageous for rodent control. However, whenever the soil is dry, porous, and sandy, some houses have dirt floors. Basic house designs give satisfactory results, such as environmentally controlled houses—which are light-tight and ventilation-controlled according to the requirements of the birds—and open houses, usually with curtains or windows. The closer the environment is to the ideal temperature, the better the rates of growth and bird health, and consequently the higher the income.

Ventilation

The two major systems to reduce high temperatures in poultry houses are tunnel ventilation and evaporative cooling cells. The main functions of ventilation are to maintain oxygen, keep carbon dioxide and noxious gas (e.g., ammonia) levels low, remove dust or moisture from the litter in the building, and maintain suitable temperatures. Proper ventilation requires management due to large variations in exterior temperatures and increasing heat production by broiler chickens as they grow (discussed in more detail in Chapter 17). Provision should be made for emergency ventilation in the event of an electric power failure. This can be done by providing sufficient auxiliary electric power (a generator) to operate fans and lights.

Relative Humidity

Performance of a broiler flock can be adversely affected by humidity (discussed in more detail in Chapter 17). A relative humidity of 60–70% appears optimal. Birds may show discomfort by huddling when the relative humidity is 45% or less. Fogging or misting is used to address very dry litter conditions, and hence increased dust, and high environmental temperatures.

Lighting

Lights are used to encourage feed and water consumption, and hence, optimize growth. Light management for broilers is very important. The type of lighting system is determined by the housing—either an open-sided or light-tight house. One suitable lighting regime is shown in Table 19.2. This consists of a very long day length with high light intensity for the first seven days followed by reductions in both day length and light intensity. The latter are thought to reduce mortalities and promote bird health. The presence of light allows normal body rhythms and behaviors and prevents aberrant behaviors such as piling or stampeding when scared.

Another system employs intermittent lighting (interrupting dark period with periods of light to enable/encourage eating but still having a period of at least 4 hours of darkness). There are advantages in the use of dawn and dusk systems with gradual changes in lighting. Whatever day length is used, it is important to avoid sudden changes in photoperiod. For the three days prior to catching, the day length should be changed to 23 hours of light per day (23L:1D).

Table 19.2 Possible system of lighting for broiler chickens.[1]

Age	Photoperiod (Day Length)	Light Intensity
Day 1–7	23L:1D	30–40 lux (3-4 fc)
After day 7	19L:5D	At least 5–10 lux (0.5–1 fc)

[1] L hours light and D hours dark.

Based on Aviagen recommendations.

Lighting sources (all emitting a spectrum of different light wavelengths) include incandescent lights, fluorescent lights, and LEDs (light-emitting diodes). Fluorescent lights are more efficient than incandescent lights but lose intensity over time. LEDs are the most efficient and consequently there is marked reduction in utility costs. However, LEDs are more expensive than incandescent and fluorescent lights.

Equipment

The two chief items of equipment within a poultry house are feeders and waterers (see Chapter 17 for details). Axillary equipment may include a mower(s) to ensure that vegetation is low enough around poultry houses to see rodent activity, front-end loaders for removal of spent litter (unless this is being performed by a contractor), and a generator in case of power interruption.

Feeders

During brooding, broiler chicks are started with additional temporary feeders (trays with feed) for the first 5 to 7 days. This allows the chicks to find feed easier. Feed should be placed in the feeders at the same time. Temporary feeders may be removed as soon as the chicks are eating from the feeders.

Inadequate numbers of feeders may result in uneven and slow growth. Moreover, it is important to have feeders at the correct height to ensure that all birds can get to the feed and there is minimal spillage (see Figure 19.4). There are different mechanical feeder types, each with specific requirements:

- Pan feeders: One feeder for 80 birds initially but increasing to one feeder per 45 birds.
- Tube feeders: 70 birds per feeder.
- Flat chain/auger: 1 inch (2.5 cm) per bird.

Waterers

It is important that broilers have at all times an adequate supply of clean, high-quality, cool water for performance, feed intake, digestion, together with bird health and welfare. Water at the point of consumption should normally be between 59–70°F (15–21°C). Types of waterers used in broiler production include the following:

- Nipple drinker—one nipple for 12 chickens (< 3–6.6 kg).
- Cup drinker.

Figure 19.4 Broiler chickens eating. (Source: Kharkhan Oleg/Shutterstock)

- Nipple drinker with cup—one nipple for 12 chickens (< 3–6.6 kg).
- Bell drinker—8 bell drinkers per 1000 chicks.

Nipple and cup drinkers are attached directly to water pipes and are triggered by birds to release water. These provide clean water in an automated system (see Figure 19.5). Bell-type waterers should be equally spaced in the house. Bell waterers should be cleaned and washed daily. In each broiler house, water should be metered. There should be sufficient water stored (together with a delivery system) to cover the eventuality of a disruption of the main supply.

Daily water consumption is a good indicator of bird health and should be recorded as part of each grower's recordkeeping. Changes in water consumption indicate either problems with the birds or with the water system.

Figure 19.5 Broiler chicks drinking. (Source: David Tadevosian/Shutterstock)

Good Water Quality

It is critically important for broiler health that the water supply is regularly checked for quality (checking for excess minerals and the unlikely possibility of pathogens).

Nutrition and Feeding

Nutrition plays a major role in the health of the broiler flock and the optimization of performance. The nutritional needs of healthy broilers are normally satisfied by the feed balanced for the required nutrients (as provided to the grower by the integrator). The processed feeds are usually mixed in a centrally located mill and delivered in bulk by truck to the broiler farm. Broiler feeds are high in both protein and energy (see Table 19.3) (see Chapters 7–9 for details).

To assure feed hygiene, feed should be heated to 191°F (86°C) for 6 minutes during processing to reduce pathogens (*E. coli* and *Salmonella* species). Pelleting does not completely kill pathogens. The feed is moved by auger from the storage tank to the automatic feeders. Care should be taken to ensure that bulk feed tanks and augers are watertight to prevent the accumulation of moldy feeds. It is also beneficial to locate feed tanks on the leeward side of the building (also see Chapters 7–9).

Table 19.3 Industry recommendation for broiler chicken feeds.

Description	Age (days)	Energy (kcal—AMEn per kg diet)	Protein (%)
Starter	0–10	3000	23
Grower	11–24	3100	21.5
Finisher	24 to market	3200	20

In Ovo Feeding

Research has found that injection of amino acids and starch into the amnion results in more rapid growth post-hatch. The chick embryos swallow nutrients, which are then digested and absorbed from the intestine. With adaptation, it may be possible to use the technology for *in ovo* vaccination to do this in an automated manner.

Form of Feed

The following are recommended:

- 0–18 days: 1.5–3 mm diameter sieved crumbles

Alternative:

- 0–10 days: mini-pellets (1.6 diameter × 2.4 mm length to 2.4 diameter × 3.0 mm length).
- 11–18 days: mini-pellets (1.6 diameter × 4.0 mm length to 2.4 diameter × 7.0 mm length).
- 18 days to finish: pellets (3 diameter × 5 mm length to 4 diameter × 8 mm length).

Feed Conversion Ratio

With improved breeding, nutrition, and management, feed conversion and growth rate of broilers are constantly improving. With narrow margins between production cost and selling price, it becomes increasingly important for the grower to pay strict attention to every step in the management program that will help improve production efficiencies.

Replacement of Antibiotics

In lieu of antibiotics, the following management practices can be employed:

1. Addition of pre- and probiotics to the feed.
2. Addition of botanicals such as oregano, rosemary, and thyme (or their oils) to the feed.
3. Reduced pH of drinking water with organic acids.
4. Extended down-time between flocks and greater focus on sanitation.

Potential replacers for antibiotics include bacteriocins (toxins produced by bacteria that kill other bacteria) and bacteriophages (specific viruses that infect bacteria).

Broiler Health

The emphasis is on disease prevention. The following are key points in any broiler health program (also see Chapter 16): biosecurity, including sanitation, disinfection, removal of dead birds, rodent control, access control (people), and access control (wild birds); "all-in, all-out" production; down time during which buildings are cleaned and sanitized; good nutrition; good environment; vaccination, medication, and parasite control. For a more detailed discussion of poultry health see Chapter 13. Presently, average cumulative mortality runs about 4%.

Good Environment

Environmental conditions contribute directly to broiler flock health. A poor environment makes birds more susceptible to disease and contributes to the spread of diseases. Adequate ventilation (good air quality with low ammonia and moisture), proper lighting, and dry litter are very important.

Poultry house ventilation requires constant attention. Most broilers are housed in environmentally controlled buildings that are mechanically ventilated. However, some broiler growers in warmer regions of the United States still use nonmechanical ventilation—curtains, panels, and windows. Agents that improve heat tolerance include betaine, glucose, and aspirin.

Wet litter is never desirable. It can be the cause of disease outbreaks or breast blisters. Moreover, excessive dust may trigger respiratory trouble. Both conditions can be avoided with proper ventilation made possible by adequate heat. Dust has sometimes been a major problem with fan ventilation, perhaps because of lower humidity and over-drying of the litter.

Sanitation and Disinfection

The producer should know what constitutes proper cleaning, why it is necessary, and how to do it. Most pathogens are killed by disinfection following thorough cleaning (see Chapter 10 for a more detailed discussion of sanitation).

Vaccination

Protecting birds by vaccinating them against diseases common to the area is good insurance against costly disease losses. Integrators have a recommended vaccination program, specifying the time to vaccinate and the type of vaccine to use.

Antibiotics and Coccidiostats

Coccidiosis, a disease caused by a single-celled organism, is an ever-present hazard when raising young chicks. In order to prevent outbreaks, coccidiostats are included in feeds and/or vaccination is performed (see Chapter 13 for a more detailed discussion of coccidiostats).

Parasite Control

A wide variety of external and internal parasites affect broiler chickens. The prevention and control of these is one of the quickest, cheapest, and most dependable methods of increasing production (see Chapter 13 for a more detailed discussion of parasites).

Management

Management is the key to success in the broiler business. The geneticist can increase the potential of production, and the nutritionist can formulate a feed that can reach this potential, but without proper care the broiler will never get there. Management can make or break a grower. Fortunately, broiler chickens respond favorably to the quality of care and overall good management they receive.

Management Practices

Good management practices include (1) starting with quality, healthy, beak-trimmed chicks from reliable sources; (2) keeping the houses and equipment clean; (3) keeping the litter clean, dry, and free from mold; (4) brooding the birds carefully and having good sanitary management; (5) supplying adequate heat and ventilation; (6) providing enough floor space; (7) giving adequate space for feeders and waterers; (8) adapting the poultry health program to local needs; (9) disposing of dead birds promptly; and (10) keeping visitors out of the houses and locking the doors. Management practices involve multiple details that add up to make broiler management very important.

Definition

Production efficiency factor (PEF) =

$$\frac{\text{Livability (percentage)} \times \text{Live weight (kg)}}{\text{Age (days)} \times \text{Feed conversion ratio (FCR)}}$$

Beak Conditioning

Cannibalism can be a problem in a broiler flock. It begins by chicks picking tail feathers, toes, vents, and can progress to other parts of the body. Beak trimming greatly reduces feather picking and cannibalism, and has little detrimental effect on bird performance. It may be done at 1 to 8 days old by trimming off less than one-third of the beak (also see Chapter 16).

Raising Males and Females Separately

Broiler chickens can be raised as straight run (males and females together) or males and females separately. In the case of the latter, broiler chicks are sexed at the hatchery. Sexing may be by vent inspection or rate of feathering; the latter only if parental stocks were specially selected and mated. Separation of sexes allows the males to be marketed first. Males are at least 1% heavier than females at hatching time, grow faster than females and weigh more at a given age, have less fat (prior to market weight with male birds having less fat), and convert feed to meat more efficiently than females. As strains are bred for increased growth, the weight variation between the males and females increases. Intermingling the sexes does not detrimentally affect growth.

Temperature

There are stringent temperature recommendations for the environment for raising broiler chickens (see Table 19.4).

The thermometer reading should be taken at the level of the chicks under the heater. With infrared lamps, readings are difficult to take. It is suggested that the lamp be hung a minimum of 18 in. (50 cm) above the floor so that the chicks form a circle. Comfortable chicks will bed down evenly or form a doughnut-shaped ring under the light. If they scatter, it is too hot. If they huddle, it is too cold.

Stocking Density

The National Chicken Council has set the following guidelines for broiler stocking density:

- 6.4 lbs per square foot (6.4 lbs ft^{-2} or 32 kg m^{-2}) in birds less than 4.5 lbs (2.04 kg).
- 7.5 lbs per square foot (6.5 lbs ft^{-2} or 37 kg m^{-2}) for birds 4.5–5.5 lbs (2.04–2.49 kg).
- 8.5 lbs per square foot (8.5 lbs ft^{-2} or 42 kg m^{-2}) in birds less than > 5.5 lbs (2.49 kg).

The European Union EU Broiler Welfare Directive (2007) recommends:

- 33 kg m^{-2} (increased to 39 kg m^{-2} with strict standards of husbandry and to 42 kg m^{-2} with very strict standards of husbandry).

Table 19.4 Temperature recommendations for rearing broiler chickens (based on Aviagen).

Age	Whole House Brooding °F (°C)	Spot Brooding Temperature °F (°C): Brooder Edge	Spot Brooding Temperature °F (°C): 2 m (6.5 ft) from Brooder Edge
1 day	86 (30)	90 (32)	84 (29)
1 week	81 (27)	81 (27)	77 (25)
2 weeks	75 (24)	77 (25)	75 (24)
3 weeks	72 (22)	73 (23)	73 (23)
4 weeks to market	68 (20)	68 (20)	68 (20)

Under hot climates:

- Housing with a controlled environment—6 lbs per square foot (6 lb ft^{-2} or 30 kg m^{-2}).
- Housing with open siding and little environmental control—4–5 lbs per square foot (4–5 lbs ft^{-2} or 20–25 kg m^{-2}). At hottest time of year, stocking density should be reduced to 3.2–3.7 lbs per square foot (3.2–3.7 lbs ft^{-2} or 16–18 kg m^{-2}).

Litter

Provide a dry, absorbent litter material 2 to 4 in. (~8 cm) deep. Dry sawdust, shavings, peat moss, vermiculite, straw, rice hulls, and other products are available. Use the one that is most convenient and economical. Litter is not usually removed following the harvesting of a broiler flock in the United States; rather, there is natural composting in the house. However, caked litter is removed after each flock. In some countries, like in Canada and the European Union, spent litter is removed after each flock. Excessive height of litter dictates the removal of some of it (also see Chapter 16).

Waste Handling

One of the major problems of broiler production is the disposal of animal waste (excreta). The best solution is to spread the excreta/litter mixture on fields as fertilizer.

Handling Mortalities

Growers are responsible for disposal of mortalities. Among the methods are composting, incineration, and deep pit burial. In the US, composting is by far the most common. Incineration is used in some states but is expensive, particularly as some states require training due to pollution issues. It is important to refer to state or country regulations, which vary considerably.

Placement

Ensuring optimal environment for placement together with ideal conditions for transportation and holding help assure maximal growth rates and mortality below 0.7% (see Table 19.5). About 75% of chicks should have their crops full 2 hours after placement. This should rise to more than 95% by 24 hours after placement and 100% by 48 hours. Litter should be 2–4 in. deep (5–10 cm).

Indices of poor chick quality include "dead on arrivals," lethargic chicks, and unhealed navels.

Brooding Broiler Chickens

In a typical grower contract, the integrator (processor or processing company) supervises the growing of the broilers and furnishes chicks, feed, and medication. The grower provides housing, equipment, and labor. The contractor decides when to market the birds and to whom they shall be sold. The contractor also outlines the brooding program to be followed (covered in detail in Chapter 16 and Figure 19.3). **Brooding is critical to the success of the grower.**

Housing

The first requirement for growing broilers is adequate housing. Since broiler production is essentially a chick-brooding operation, the house must control such factors as temperature, moisture, air movement, and light. Whatever the location, houses should be capable of maintaining a temperature of > 70°F (> 21°C) throughout the year.

Brooders

The type of brooder to use varies (see Chapter 16). Brooder guards to keep chicks confined to the brooding

Table 19.5 Requirement for holding, transportation, and placement of chicks.

	Temperature °F (°C)	Relative Humidity %	Air Exchange	Vent Temperature	Feed and Water Available
Holding and Transportation	71.6–81.4 (22–28)	50	0.71 m^3/min/1000 chicks (25 cubic foot per minute per 1000 chicks)	103–105 (39.4–40.5)	No
Placement[1]	Air: 86 (30) Litter: 82.4–86 (28–30)	60–70	Sufficient to achieve desired environment	103–105 (39.4–40.5)	Yes

[1] Preheat for 24 hours.

area are recommended by some manufacturers. Corrugated cardboard 14 to 18 in. (~40 cm) high may be used particularly in winter, not only to confine the chicks but to aid in preventing floor drafts. Poultry netting may be used to replace cardboard for summer brooding. The guards should extend out about 3 ft (1 m) from the edge of the brooder to allow the chicks to move out from under the brooder if they become too hot. The guard may be removed after about the first week.

Feeding Equipment

Broilers are started with supplementary feed to allow them to find the feed more easily. Temporary feeders may be removed as soon as chicks are eating from the troughs. Mechanical feeders are generally used.

Waterers/Drinkers

Adequate watering space is essential (see Chapter 17).

Vaccination

Protecting broilers by vaccinating against diseases common to the area is good insurance against costly disease losses. Marek's vaccine is usually administered at the hatchery (*in ovo* or at 1 day old) (also see Chapter 13). Immunization against both Newcastle and infectious bronchitis should be between the first and fourteenth day of age. Intraocular or intranasal dust, spray, and water-type vaccines are available; hence, the method that has given the most suitable results should be used. Booster vaccinations for Newcastle may be given when the birds are 4 to 5 weeks old.

Litter

Broilers may be provided with fresh or reused dry, absorbent material 2 to 4 in. (~8 cm) deep. Wood shavings, sawdust, straw, rice hulls, and other products may be used. The choice of the litter should be made on the basis of what is most convenient and economical.

Light

All-night lights (3.5–5 lux/0.35 to 0.50 foot-candle at bird level) will give a big assist in keeping the birds from crowding in corners or piling up in case of disturbance during the night, and will tend to increase feed consumption, especially during hot weather.

Temperature

The brooder temperature should be 95°F (35°C) at the edge of the hover, 2 in. (5 cm) above the litter. In controlled-environment houses, however, satisfactory results can be obtained with starting temperatures as low as 88°F (31°C).

In Case of Trouble

If the birds go off feed or if there is a sudden increase in mortality, immediate steps should be taken to determine the trouble. It is best to have a positive disease diagnosis before any treatment is started. To this end, mortalities should be sent to a diagnostic laboratory.

Harvesting or Pre-Slaughter Harvesting or Catching

For the three days prior to catching, the day length should be changed to 23 hours of light per day (23L:1D). Growers withdraw feed six hours prior to the scheduled arrival of the catchers (employed by the integrator). Crews of catchers travel to a grower's poultry facilities and place all the chickens into clean crates (discussed in more detail below in section 19.6). This is consistent with the "all-in, all-out" approach.

Down Time

At least one week is required between flocks to clean, disinfect, remove litter (unless litter is being recycled), and prepare for the next batch of chicks. This is referred to as "down time." Down time needs to be extended for antibiotic-free production.

19.6 Broiler Chicken Processing

Most broilers are marketed when they are between 6 and 8 weeks of age. Marketing involves moving the birds from the poultry house(s) in which they are raised to the processing plant. Improper handling of broilers immediately prior to and during shipment will result in deaths, excess bruises, and lowered quality.

The feeders should be removed at least 4 hours before the catching crew arrives so that the intestines are empty during processing. Removing or elevating feeding and watering equipment will prevent bruises during catching. (It is not important whether or not that waterers are removed as drinking occurs at the same time as eating.)

Catching Birds/Harvesting

Chickens are caught by hand and placed into crates by a loading crew of seven to ten people. Typically, catchers pick up the birds by their legs. It is possible to catch them without injuring or damaging the birds. Welfare and economic considerations dictate that the crew be well supervised with incentives to do the job right. Catching requires the following:

1. Using an experienced, well-supervised crew.
2. Working under a dim light at night.
3. Corralling birds in small groups (of about 200) to prevent smothering and undue injury.
4. Grasping birds by the shanks, with no more than four or five being carried at a time.
5. Placing the birds in the crates gently.
6. Handling the crates carefully, preferably on pallets that can be moved easily with a hoist.

Improved pre-slaughter harvesting requires training of personnel, proper catching, supervision of personnel, speed, feed withdrawal, reduced light intensity, distributing and loading cages by winching, and organizing filled cages in the transporter.

Catching may become automated with mechanical harvesting. This involves the use of a "catcher" or "harvester" of rubber paddles or fingers together with a conveyer belt to the transporter. Advantages of mechanical harvesting include lower stress to birds, fewer bruises, reduced labor costs, and improved working conditions for the catching crew.

Transportation/Holding

Poultry are hand-loaded into loose crates (plastic), fixed crates, or modular containers and then transported from the production unit to the processor in trucks. Each crate or container can hold about 14 birds. Transportation may represent a 3- to 5-hour journey and up to 12 hours in holding (or lairage). Birds are stressed during transportation due to vibration, lack of food and water, environmental temperatures, and lack of space. It is important to protect the in-transit birds from extremes in weather such as chilling in cold weather or overheating in hot weather to reduce "dead on arrivals."

Care is taken to moderate extremes of temperatures and mitigate against their effects during both transportation and holding. This includes avoiding overfilling during transportation and providing ventilation during transportation by fans. Measures taken during holding include parking under cover and the use of foggers during hot weather. *Campylobacter* and other pathogens can be spread in broiler transporter coops. Some bird deaths occur during transportation. Shrinkage, or weight loss from the time feed and water are removed until the birds are weighed at the processing plant, varies according to temperature and length of time involved; it ranges from 2% for a 3-hour period to 6% for a 15-hour period.

Processing

There has been an increasing trend for further processing of chicken (see Table 19.6).

Table 19.6 Changes in the marketing of chicken between whole chickens, cut-up birds, and further processing.

Year	Whole Chicken	Cut Up (Breasts, Wings, Thighs, and Legs)	Further Processed
1970	70%	26%	4%
1990	18%	56%	26%
2010	12%	43%	45%

Slaughter and Processing

The slaughter and processing of broilers is an assembly-line operation conducted under sanitary conditions (see Figures 19.6 through 19.8). The steps for slaughter and processing are (1) unloading birds from the transport vehicle, (2) shackling to a conveying chain, (3) stunning, (4) killing by cutting throat and by severing the jugular vein, (5) bleed out, (6) scalding, (7) feather removal, (8) removal of oil gland and feet, (9) evisceration, (10) removal of crop, head, and lungs, (11) washing, and (12) cooling. Large processing plants are more efficient.

Steps in the Processing of Broiler Chickens

1. **Unloading chickens** from the transporter after holding. This can be performed manually or the process is automated with a tilt system. Birds are moved to the shackling line from the crates or containers. Unloading the birds is again usually done by hand. Automated unloading has been developed by use of conveyer belts. Care needs to be taken during unloading to prevent bruising.
2. **Shackling.** Birds are placed head down with the shackles under their knee joints. Unloading birds is again usually done by being hung upside down by their feet on shackles onto the automated lines.
3. **Stunning**. In conventional processing, the bird is rendered unconscious by the stunner. This can be achieved by electrical stunning. An alternative method of stunning is exposing the birds to specific mixtures of atmospheric gases to render the birds unconscious. There is increasing use of gas

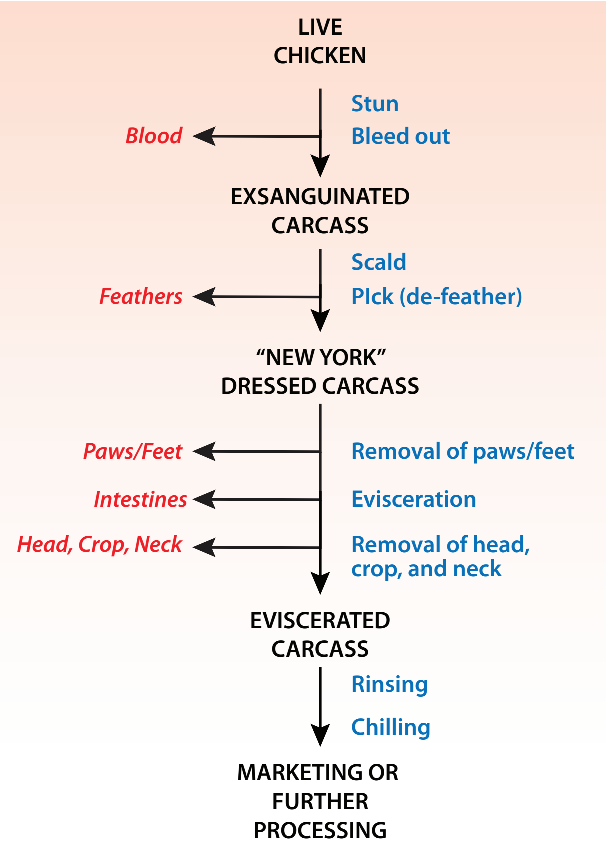


Figure 19.6 Overview of poultry processing.

Figure 19.7 Chickens in shackles on the line in a poultry processing plant. (Source: Sergey Bogdanov/Shutterstock)

Figure 19.8 Raw dressed chicken at the end of processing. (Source: JIANG HONGYAN/Shutterstock)

stunning. Stunning is not permitted in Kosher chicken (discussed below).

4. **Killing and bleeding.** This is accomplished using an automated knife that cuts major blood vessels (either one or both carotid artery and jugular vein) and hence kills the chicken. Bleeding out takes between 2 and 5 minutes with about 40–50% of the entire blood volume removed from the carcass. Bleed time needs to be increased at high altitudes. If there is not adequate bleeding the carcass appears reddened.
5. **Scalding.** Carcasses are submerged under hot water [122–127°F/50–53°C] for 1–3 minutes in the scalder to loosen the feathers. Aeration increases the mixing of the water, maintenance of uniform temperatures, penetration of the feathers by the scalding water, and hence, aids picking. Scalding can be achieved by steam scalding. In **soft** or **semi-scalding**, broiler chicken or turkey carcasses are submerged under hot water [122–127°F (50–53°C)] for 1–3 minutes; sub or medium scalding is used for large turkeys and other large birds with submerging carcasses at 129–136°F (54–58°C)] for 1–2 minutes; hard scalding is used for waterfowl with submerging carcasses at 138–142°F (59–61°C)] for 45–90 seconds. Scalding at higher temperatures results in easier removal of the feathers and loss of the epidermis in the picker. This can lighten the color of the skin and reduce the yellow coloration. Carcasses can be lost in the scalder. To control this, it is important to determine the number of birds on shackles before and after the scalder. Scalding is not permitted for Kosher chicken.

6. **Picking or defeathering or removal of feathers or plucking.** Feather removal is achieved by mechanical pickers and pluckers. This is accomplished by rubber projections or fingers on rotating disks in the picker. Next, the oil gland and feet are removed under rotating blades and bars/rails position the bird for cutting.
7. **Removal of feet (paws), head, and neck.** Feet are removed at the ankle joint by circular blades. After removal of the feet, the carcasses have to be hung on a new and clean line by shackles.
8. **Evisceration** (removal of intestines). This can be performed manually, semi-automatically, or automatically (the latter being the major method in the United States). The viscera are removed in a manner not to influence the integrity of the intestinal wall, i.e., **do not pierce the wall** and release any gut contents and, hence, do not cause microbial (including pathogens) contamination of carcasses. Inspect the viscera for signs of disease. Diseased birds are condemned. Giblets—edible viscera consisting of the heart, liver, and gizzard—can be retained and placed into the carcass in a plastic bag. Other viscera are rendered.
9. **Head, crop, neck, and lungs are removed** after evisceration in many plants. The carcasses are rehung on another shackle line automatically.
10. **Washing/cleaning and rinsing with spray nozzles.** This entails removing extraneous materials from the abdominal cavity and carcass surface and, thereby, reducing microbial contamination. This is followed by ensuring complete drainage.
11. **Chilling** brings the carcass to a low temperature, specifically 40°F (4.4°C), in the chiller. To reduce microbial contamination in the chiller, carcasses are exposed to antimicrobials—chloride and peracetic acid (CH_3CO_3H). These measures are to prevent microbial growth, prevent spoilage and improve food safety (but are not permitted in the European Union). The chiller usually contains ice water but can be air cooled or air spray cooled. According to the United States Department of Agriculture's (USDA) Food Safety and Inspection Service (FSIS), the time required in the chiller for US processors is 4 hours (< 4 lb; < 1.81 kg), 6 hours (4–8 lb; 1.81–3.63 kg), and 8 hours (> 8 lb; > 3.63 kg). Although, broiler chickens need to cooled to 40°F (4.4°C) by the end of their time in the chiller, turkeys have a waiver on this requirement. After the chiller, the carcass drains with the amount of water permitted to be retained regulated.

Changes in Weight during Processing

During processing there is about a 30% loss of weight from the loss of blood and removal of feathers, intestines, and head. There is then up to 9% gains during chilling; and dressing percentage is higher with males and larger birds.

Controlled Atmosphere Stunning

Controlled atmosphere stunning irreversibly induces poultry to a state of insensibility. Controlled atmosphere stunning is achieved by increasing the carbon dioxide partial pressure, by very low oxygen partial pressure, or both. Some processors (including Cargill Protein, Perdue Farms, and Tyson Foods) in North America have invested in controlled atmosphere stunning systems. Birds are placed in these stunners from the transporters. After stunning, the birds are placed in the shackles. Temple Grandin (2013) has argued for the benefits of the approach stating that "electrical stunning provides instant insensibility, but live shackling is definitely bad for bird welfare." The available evidence from research is broadly supportive that controlled atmospheric stunning is humane.

Importance in Cleaning and Antimicrobials

It is critically important for thorough cleaning and disinfecting throughout poultry processing plants. This includes using antimicrobials. Those approved by the USDA in poultry processing plants include chlorine (sodium hypochlorite) and sodium thiosulfate. The antimicrobials are used to neutralize biofilms; the latter harboring microbes including pathogens.

Ventilation in Poultry Plants

Air flow in poultry processing plants is from clean areas to dirty areas to reduce contamination of poultry.

New York Dressing

New York dressing was the way that chickens were sold 50 years ago. This entailed selling after killing, bleeding, and removal of feathers (colloquially known as "dead and bled"). These birds are sold without being eviscerated. In the New York room of a poultry processing plant, birds have been killed, bled, and the feathers have been removed.

Inspection by the Food Safety and Inspection Service (FSIS)

Meat cannot be sold in the United States without USDA inspection. Inspection is conducted by the USDA's public health agency, the Food Safety and Inspection Service (FSIS). The method of on-line inspection is a visual (organoleptic) method with examination of both viscera and carcass. FSIS inspection systems for broiler chickens are the following:

- New Equipment Line Speed (NELS) Inspection System allows a line speed of 91 birds per minute but with four USDA inspectors per line and one on the floor; at least one in the middle and one at the end of the line. The NELS is the "fall-back" position.
- New Poultry Inspection System (NPIS) allows a line speed of 140 birds per minute with two USDA inspectors per line; one in the middle and one at the end of the line together with four company sorters.
- HACCP-based Inspection Models Project (HIMP) with one inspector at the end of the line before the chiller. Plant employees inspect and remove contaminated birds from the line with inspectors conducting verification and system inspections (less than 20 plants in the United States use this system). USDA train company personnel who inspect carcasses.

Turkeys are inspected predominantly by the NPIS.

Condemnations

Carcasses failing inspection are considered as condemned or as condemnations and are removed from the line. They are included with the offal for rendering. Downgrades and condemnations are economic losses. Rates of condemnation have declined markedly. For instance, in the United States between 2000 and 2015, the rates of condemnation of poultry carcasses have decreased from 1.8% to 0.2%.

Plant condemnations can be due to blood in meat, contact dermatitis (reddening of a patch of skin), cellulites (end of scratch contaminated with *E. coli*), fractures and dislocations, gastrointestinal/ingesta contamination, hematoma (blood collected outside a blood vessel), muscle disorders (e.g., breast myopathy, white striping, or woody breast), or scratches. Issues with chicken meat include woody breast (see Figure 19.9). This is a condition that reduces the eating quality of the chicken.

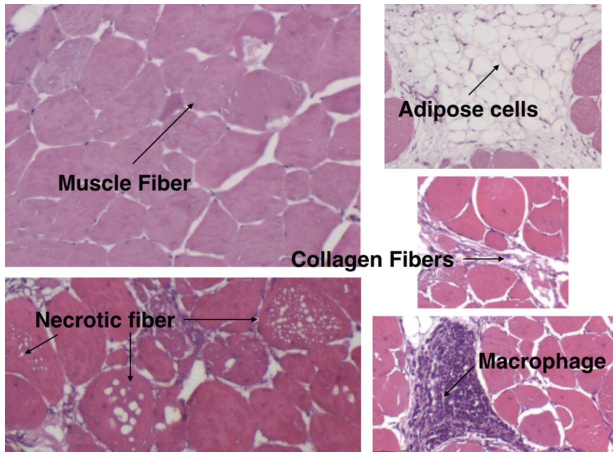


Figure 19.9 Histological analysis of chicken breast showing large muscle fibers (top left) and images of woody breast with necrotic muscle fibers (disintegrating fibers) and invasion of muscle tissue with collagen fibers, adipose cells, and macrophage. (Images kindly provided by Dr. Sandra Velleman, The Ohio State University.)

Viscera and Other By-Products for Rendering

Viscera, condemnations, necks, bones, etc., are transported to rendering facilities where they are rendered.

Problems with Meat Quality

There can be problems with meat quality in large broiler chickens and hence such products as jumbo fillets. This is described by various myopathies such as woody breast. This leads to customer complaints due to decreased protein functionality. Customers greatly value tenderness of meat.

Kosher Poultry Processing

Shechita(h) is ritual slaughtering of animals that follows Jewish religious law and specifically the Torah. It involves killing every bird by hand with a single sweep of a sharp knife. This severs the carotid arteries and jugular veins together with the trachea and esophagus. There is no stunning. Death is by blood loss or exsanguination. The person

Textbox 19C

A Deeper Dive: Rendering

The process of rendering converts supposed waste products into safe, useful by-products. The process includes the application of heat to cook poultry by-products, thereby killing pathogens including bacteria, viruses, and single-celled parasites. There are over 270 rendering facilities in the US. Rendering facilities follow Good Manufacturing Practice.

Following cooking, the product is pressed to reduce water content and then subjected to grinding. Fat is separated and stabilized by the addition of an antioxidant. The products are tested to assure that the concentrations of pesticide residues and polychlorinated biphenyls are below specified levels. The following are several by-products rendered from poultry processing:

1. **Poultry by-product meal (PBM)**. Offal (from evisceration), necks, feet, and condemnations largely rendered to chicken meal. This can be used in feed for poultry and livestock (for composition of PBM see Textbox 19C Table 1).
2. **Blood meal (flash dried)**. Blood from exsanguination is rendered and flash dried to produce blood meal. This can be used in poultry and livestock feed.
3. **Hydrolyzed poultry feather meal**. Feathers from the picker are rendered (hydrolyzed) by heating under pressure to produce hydrolyzed poultry feather meal. This can be used in livestock feed due to its digestibility. Feather meal can be used as an organic nitrogen fertilizer for gardens.
4. **Bone meal**. Bone from deboning in further processing of poultry carcasses is rendered to bone meal. Bone meal is used in livestock feed and pet foods.
5. **Poultry fat**. There is about 1.1 million tons (1.0 million metric tons) of poultry fat produced in the US each year. It is used in pet food, feed for livestock and poultry, and for industrial purposes including biodiesel.

Textbox 19C Table 1 Composition of various poultry by-products.

	Crude protein (%)	TMEN, kcal/kg (fat %)	Phosphorus	Calcium
Poultry by-product meal (PBM)	60	3,120 (13)	1.7	3
Blood meal	90	3,625 (1)	0.3	0.4
Feather meal	81	3,276 (7)	0.5	0.3

Based on Meeker and Hamilton, 2006.

conducting the slaughtering is called a shochet or kosher slaughterer. The individual must be a pious Jew, proficient in the technique and, usually, has written authorization by a rabbinical authority.

Liver has a high content of blood but can be koshered by a specific process within 72 hours of ritual slaughter. This includes careful washing to remove any visible blood followed by broiling on wire over an open flame (rotating several times) so that any fluids drop into the fire. After broiling, the liver should be washed three times. The uncooked and unwashed liver should not come in contact with kosher utensils, plates, etc.

Halal Processing

Halal poultry processing involves the processing plant being accredited by a Muslim imam, an oral prayer before the start of processing, and slaughtering by a Muslim (in some cases, supervision of slaughtering by a Muslim is sufficient). Stunning prior to bleeding can be permissible.

حلال
HALAL

19.7 Broiler Breeders and Reproduction

The goals of broiler breeder rearing are (1) broiler breeder health and, hence, low mortality (see Table 19.7), (2) high production of fertile eggs and, hence, quality chicks, and (3) economical/low feed consumption. There must be rigorous standards of biosecurity, sanitation, and animal welfare. Performance goals for broiler breeders are shown in Table 19.7.

Table 19.7 Performance goals of broiler breeders.

	Ross 308	Ross 708
Total Eggs	182	173
Hatching Percentage	84.8%	85.8%
Peak Egg Production	85.7%	82.4%
Age at Depletion	64 weeks	64 weeks
Mortality and Culls—Rear Period	4–5%	4–5%
Mortality Laying Period	8%	8%
Body Weight at 25 weeks	3.0 kg	2.7 kg
Body Weight at Depletion	4.1 kg	3.9 kg
Feed per 100 Chicks	31.9 kg	38.6 kg

Data from Aviagen.

The three phases in management of broiler breeders are brooding (1–7 days) in the rearing house, rearing (1–21 weeks) in the rearing house, and laying (week 21 onwards) in the layer house. During this phase, adult males and females are normally housed together so that insemination can occur.

Breeding and Genetics

The key to the success of broiler production worldwide is the tremendous improvements in the growth rate and, consequently, feed efficiency achieved by poultry breeders. Broiler breeder flocks consist of a female line and a male line. The male lines have dominant white feathers and are selected for rapid growth, meat characteristics such as breast width and carcass yield, livability, and rapid feathering. Female lines used in producing broilers must have outstanding growth rate, high hatchability, and good, but not necessarily outstanding, production of eggs of desirable size and texture. If male and female lines differ, as they often do, each line must cross well with other lines if it is to remain competitive. The breeder must determine the ability of male and female lines to cross well, whether the lines are developed by separate breeders or the same breeder.

Housing

There are different types of systems for rearing pullets for broiler breeders and to house broiler breeders:

1. Closed environmentally controlled rearing house + Closed environmentally controlled layer houses.
2. Closed environmentally controlled rearing house (blackout house) + Open-sided layer houses.
3. Open-sided rearing house + Open-sided layer houses.

Biosecurity

Standards for biosecurity for broiler breeders (parent stock) must be even higher than those for broiler chickens (see Chapter 16 for a detailed discussion). Biosecurity encompasses a written biosecurity plan; personal training; strict visitor policies; sanitation; rodent, insect and wild bird control; and "all-in, all-out" one flock at a time (all birds are of a single age) at a single site.

Sanitation

Sanitation is critical. This entails washing with disinfectants. Floor treatments include boric acid to reduce darkling beetles; salt to reduce pathogens such as *Clostridium*; sulfur powder to act as a fungicide, insecticide, and acaricide, and to reduce litter pH.

Drinking Water

Drinking water should be tested for both *Pseudomonas* species and *E. coli*. If not mains/city water, water should be chlorinated to 3–5 ppm chlorine.

Brooding

This is from day 1 (as soon as the chicks arrive on the farm) to 7 days of age. The arrangements for brooding need to be established before the anticipated arrival of the chicks and are similar to those for broiler chickens (see Section 19.5 and Chapter 16). These include critical temperatures, ventilation, and fresh litter. It is essential to have bird comfort throughout brooding. Moreover, it is important to ensure that carbon dioxide levels are less than 3000 ppm (brooding). From the day-old chick stage to photostimulation, males and females are normally reared separately.

Raising

The three phases in raising broiler breeders are early growth (1–6 weeks old), maintenance (6–16 weeks old) with a strict limitation to feed intake, and transition (16–21 weeks old).

Lighting

Day length is strictly controlled during raising (Table 19.8). Light intensities are usually between 5 and 10 lux (0.5–10 fc). For open-sided rearing houses, blackout curtains should be closed during the transition phase. It is important that the photoperiod be 8 hours of light per day from 15 to 21 weeks old to break photorefractoriness and allow photostimulation of reproduction after transfer to the layer house. Birds are

Table 19.8 Day length recommendations for parent lines during growth.

Age	Day Length	Light Intensity in Lux (Foot Candles)[1]
Days 1 and 2	23L:1D (23 hours of light per day)	80–100 (8–10)
Day 3	19L:5D (19 hours of light)	80–100 (8–10)
Day 4	16L:8D (16 hours of light)	80–100 (8–10)
Day 5	14L:10D (14 hours of light)	80–100 (8–10)
Day 6	12L:12D (12 hours of light)	30–60 (3–6)
Day 7	11L:13D (11 hours of light)	30–60 (3–6)
Day 8	10L:14D (10 hours of light)	30–60 (3–6)
Day 9	9L:15D (9 hours of light)	30–60 (3–6)
Day 10–Week 21	8L:16D (9 hours of light)	10–20 (1–2)

[1] Data shown in brooding area. Rest of house—10–20 lux (1–2 foot candles).

photostimulated (with increasing day lengths) at 21 weeks old, inducing sexual maturation. For a conceptual view of the photoperiodic control of reproduction see Figure 19.10.

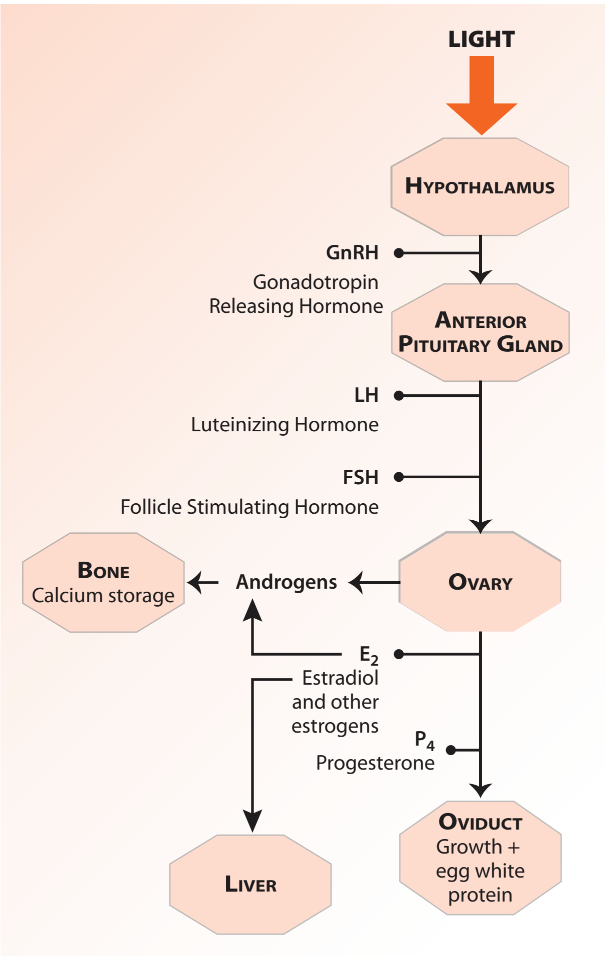


Figure 19.10 Conceptual view of how light brings broiler breeders into reproductive condition (photostimulation of reproduction).

Broiler Breeder Pullet and Young Male Nutrition

Nutritional requirements and practices for feeding the growing and adult broiler breeder show differences from both the broiler and laying chicken. Feed allocation to attain target body weight goals is adjusted weekly following weighing representative birds. The target body weight is markedly below the potential of the bird so the amount of feed has to be restricted. There are different target body weight goals for males and females. This can be achieved by such means as "skip-a-day" feeding. Feed should be distributed rapidly so that all birds have access to it. The composition of feeds for different life stages of broiler breeders is shown in Table 19.9.

Nutrition during Growth of Broiler Breeder Pullets

Feed intake is restricted during growth of broiler breeder pullets. This is done to produce smaller, leaner hens with lower maintenance requirements. Feed is restricted by either reducing the feed provided each day or feeding on alternate days ("skip-a-day" feeding). In either system, broiler diets can be employed, such as shown in Table 19.9. The restriction on feeding begins at about 4 weeks of age.

Advantages of feed restriction during growth include reduced feed costs during growth, reduced feed costs during egg production, reduced mortality during rearing and egg production, and little effect on the number of eggs produced while also producing larger eggs.

Disadvantages of feed restriction during growth include delay in initiation of egg production, welfare

Table 19.9 Nutrient requirements for different stages of broiler breeders.

Life Stage	Energy (kcal per kg/MJ per kg)	Protein (% Crude)	Calcium (%)
Starter (female)	2800 (11.7)	19	1.0
Grower (female)	2800 (11.7)	14–15	0.9
Female breeder (5% production to 35 weeks)	2800 (11.7)	15	3.0
Female (breeder) (35–50 weeks)	2800 (11.7)	14	3.2
Female (breeder) (after 50 weeks)	2800 (11.7)	13	3.4
Male (breeder)	2700 (11.3)	11.5	0.7

issues, and public perception. If a broiler breeder pullet received a high energy/high-protein diet ad libitum during growth, body weight would be 9.5 lb (4.3 kg) at 24 weeks old in comparison with the ideal with feed restriction of about 5 lb (2.3 kg)!

Nutrition during Growth of Broiler Breeder Males

The diet for growing male broiler breeders is restricted to prevent obesity, using skip-a-day and daily restriction approaches.

Laying Stage

The laying house is furnished with waterers, feeders (separate for males and females), nests, and perches. The laying stage is divided into the pre-laying phase and the laying phase.

It is important to ensure that the breeder house is cleaned and completely ready to receive birds. Broiler breeders are transferred to breeder houses between 18–23 weeks old (average is 21 weeks old). Males are moved in one day before females. Birds are moved such that there is sufficient time for birds to eat and drink before lights out. (It is advisable to check on this by feeling whether the crop is filled in about 100 birds). Males and females are together in the layer house for "mating up" between sexually mature males and females. Males and females are fed separately. This is accomplished by placing grills over the hen feeders such that the males cannot enter the female feeders (males are bigger than females) or male heads cannot enter the feeder due to their combs.

Ratio of Males to Females

The optimal ratio of males to females is 1:20 and then phased adding more males to 1:15 and then 1:10. If there are fertility problems, poor performing males are culled to be replaced by younger males in what is called "spiking."

Lighting during the Laying Stage

In the rearing house the birds are photostimulated to induce reproductive development (see Table 19.8). This means the day length is increased, the hypothalamus is then activated to release gonadotropin-releasing hormone (GnRH); the anterior pituitary gland is provoked to release the gonadotropic hormones, luteinizing hormone (LH) and follicle stimulating hormone (FSH); and the gonads undergo growth, maturation, and produce sex hormones.

In the hen, the development of follicles in the ovary starts leading to the production of the sex hormones progesterone (P_4), estradiol (E_2), and other estrogens together with androgens. In males, the testes develop, spermatozoa production is initiated and the androgen, testosterone, is produced.

Sex hormones have effects, for instance on the ducts. In females, estrogens cause the liver to produce yolk proteins, the oviduct to develop and produce egg white proteins (with P_4), and calcium to be deposited in the bones (with androgens). In males, androgens cause the growth of the comb and wattle (sexually mature males have bright red wattles and combs) and the appearance of male behavior including libido (desire to mate) and aggression.

The **day lengths** in the layer house should be the following:

- Week 21—11L:13D.
- Week 22—12L:12D.
- Week 23 onwards—13L:11D.
- Alternative Week 21 onwards—13L:11D.

Day lengths of greater than 14L:10D do not have benefits and can result in photorefractoriness with reduced egg production. Light intensities during laying (photostimulation until cessation of economically viable egg production) should be 30–60 lux (3–6 foot candles). The day length in the rearing house prior to transfer to the layer house is 8L:16D.

Definitions

Photostimulation: The induction of a physiological process (such as reproduction) by long day lengths (see Figure 19.10).

Photorefractoriness: When an animal or plant no longer responds to a stimulatory photoperiod. A period on short day lengths is required to break photorefractoriness.

Depletion: The end of productive egg production in broiler breeders. This is due at least in part to photorefractoriness.

Day length or **Daily photoperiod:** An example of a photoperiod is 11L:13D. This is equal to 11 hours of lights on (day) and 13 hours of lights off (night).

Photophase: The time of light, or lights on, or subjective day. It is sometimes but erroneously called the photoperiod.

Scotophase: This is the time of darkness, or lights off, or subjective night. It sometimes but erroneously is called the scotoperiod. The light intensity during the scotophase should be less than 0.4 lux or 0.04 foot candles.

Photoreception: This is the action of light on specific photosensitive proteins (e.g., opsins) in photosensitive cells such as in the eye. Interaction of light with the photosensitive proteins leads to changes in the cell (signal transduction).

Broiler Breeder Hens

The broiler breeder hen produces eggs for a shorter period than laying hens. Moreover, in the older broiler breeder (> 1 year old), the daily egg-laying cycle becomes irregular and the number of soft-shelled eggs increases. Egg production in the broiler breeder shows peaks during weeks 6–10, with production at about 75%, and declines thereafter (e.g., at 40 weeks of production) at 60%.

Eggs

Nests

Birds need to be encouraged to lay in the provided nests. Eggs laid on the floor are called "floor eggs." These represent an economic loss versus nest eggs. Eggs are collected at least twice daily.

Egg Storage

The longer eggs are stored, the greater the percentage of embryonic mortalities, the lower the overall hatchability, and the reduction in albumen quality (see Chapter 15).

Egg Incubation

The temperature for incubation of chicken eggs including broilers is 100°F (37.8°C).

Egg Size

Since broiler chickens go to market at progressively younger ages, growth of the embryo (or *in ovo* growth) becomes increasingly important. Growth in the egg is more than 30% of growth (3 weeks or 21 days as a percentage of 3 weeks' embryonic growth plus 6.5 weeks posthatch growth). Broiler chicks from large eggs are larger at hatching than those from small eggs. As broilers grow, the effect of this relationship continues.

Sexing (Separation of Male from Female Chicks)

Chicks can be sexed (gender determined) by vent inspection and the sex-linked pattern of feathering on wings. It is possible that an experimental method of automated sexing will be adopted. This involves taking a small sample of allantois fluid at about day 15 of incubation. Fluid with high levels of estrogen conjugate comes from female chick embryos. The gender of the embryo is thus determined and the egg sorted by gender before hatching.

Broiler Breeder Males

Full semen quality, as determined by the sperm quality index, is achieved at about 30 weeks of age in broiler breeders. There are age-related diseases in male fertility/semen quality, leading to the frequent practice of replacing males by approximately 1 year of age. Some chicken breeders use artificial insemination (also see Chapter 4).

Artificial Insemination

Artificial insemination is used with some broiler breeders. The advantages include increased fertility, reduced damage to females during mating, discontinued use of large males that may have difficulty mating, allows the separation of males and females, evaluation of semen can for quality (e.g., spermatozoa motility and number of abnormal spermatozoa), and semen can be diluted or extended. Insemination can occur every 10 to 14 days as spermatozoa are stored in the oviduct. The optimal dose of sperm per insemination has been estimated as about 150 million every 5 to 7 days. The disadvantages of AI are the costs, including labor requirements.

Semen Quality

The sperm quality index (SQI) is a measure of semen quality. It is determined by deflection of a beam of light due to movement of the spermatozoa.

Nutrition of the Broiler Breeder Hen

The broiler breeder hens have a calcium-rich (initially 3.0%) feed freely available. In addition, calcium-containing crushed oyster shell may be available. The calcium is for eggshell production and building calcium stores in the medullary bone (stimulated by the hormone estradiol and other estrogens together with androgens) prior to egg production.

Broiler Breeder Males (Roosters)

The diets for broiler breeder roosters should be lower in protein plus calcium and somewhat lower in energy than hens (see Table 19.9).

Management

It is important to have superior management and care for the broiler breeders. This includes keeping records of egg production daily, environmental temperature daily, any mortalities (daily, weekly, and cumulative), and body weight gain for representative birds in the flock.

19.8 Other Poultry Products

By-Products

Pet Food

Pet food represents a considerable and expanding market for poultry meat and poultry by-products—the rendered material from offal in pet food. Dog and cat food are available as canned soft food, dry food, or semisoft dry food. Dollar sales of cat and dog food are increasing by about 4% in the United States, with similar growth elsewhere. Pet food uses poultry meat and poultry by-products. An estimate of use of poultry by-products worldwide is approaching 1 million tons per year (~1 million metric tons/year).

Feathers

Feathers are a useful by-product of the production of poultry meat, with feathers being 7% of the live-weight of poultry. The biology of feathers is discussed in Chapter 4. Feathers can be classified as down (fluff only with no shaft), partial down with some shaft (e.g., plumbs, fluff, three-quarter, half-fluff), or hard and saddle feathers. Major uses are for insulation and comfort or as feather meal for animal feed. Feathers are very useful for bedding and winter clothes. They are a natural, durable product; are biodegradable; are comfortable; and, because of the amount of air trapped, they are excellent lightweight insulators.

Down feathers are separated from the rest of the feathers by flowing with their low density in air. They can travel farther while the other feathers settle out. The best feathers are used in sporting equipment (e.g., arrows and darts). Feathers must be washed (5–8 times) in soap to eliminate animal waste, but some oils should be left attached. They may also be treated with a salt solution and dilute acid.

While feathers are principally made of the protein keratin, they are not digestible. However, with high-pressure cooking at > 212°F (> 100°C), hydrolysis occurs, increasing the availability of amino acids. Feather meal is produced following drying and grinding of the hydrolyzed feather. It can be added to poultry or swine or ruminant feeds, being a good source of arginine, cysteine, and threonine. Feather meal has 75–90% crude protein.

Offal and Bone

Bone and offal consist of edible offal (liver, hearts, and gizzard—collectively called giblets) and inedible offal, such as the rest of the gastrointestinal tract (head, feed, bone from deboned poultry meats), lungs, and kidneys. Blood may be considered as either edible or inedible offal. Inedible offal is rendered by cooking at high temperatures (212°F; 100°C) under pressure to destroy pathogenic organisms. The resulting material can be used for livestock feed or pet food.

Specialty Chickens

There is an increasing interest in specialty chickens. These include organic chickens; pasture chickens; label rouge using SASSO chickens; capons; slow-growth chickens using slow-growing lines, such as Rowan Range (these are, for instance, sold at Whole Foods); and combinations of the above. Despite some consumer demand, there is evidence that slow-growth chickens have a greater impact on the environment. Specialty chickens are discussed in detail in Chapter 3.

Capons

In the past, capons were a popular chicken meat. Capons are surgically castrated male chickens. The objective of caponizing is to improve the quality of the meat produced. Capons do not develop the normal male characteristics such as the head, comb, and wattles. They do not crow or fight like roosters, and the dark meat of capons is lighter-colored than meat of males of the same age. When marketed, they range up to 20 weeks of age and weigh > 12 lb (5.5 kg). Slow-growing breeds are now being used and becoming more popular. The breeds and crosses used for broiler production make satisfactory capons. Diets for broiler chickens are also satisfactory for capons.

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20

Turkeys and Turkey Meat

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. List the major regions producing turkey meat.
2. List the top turkey processing companies in the United States.
3. Know the dynamics of global turkey production.
4. List the major weights and ages at which turkeys are marketed.
5. List the basic composition of turkey meat.
6. List the major breeders of commercial turkeys.
7. List the major varieties of exhibition turkeys popular in North America.
8. Give recommendations on the rearing and production of turkeys.
9. List the major diseases encountered in turkey production.
10. Know the products created from the further processing of turkeys.
11. Define photostimulation and give recommendations on utilizing this concept to improve egg production in turkey breeders.
12. Give reasons and recommendations for artificial insemination in turkeys.
13. Know the characteristics of high quality semen.
14. Know the characteristics of poor quality semen and what happens to toms that produce poor quality semen.
15. Give suggestions for maximizing fertility and hatchability of turkey eggs.
16. Explain why carbon dioxide/incubator ventilation is important to incubation.
17. Know what actions are taken at the hatchery for newly hatched poults.

20.1 Introduction

Wild turkeys (*Meleagris gallopavo*) are native to North America (Figure 20.1). Turkeys are one of the few animals domesticated in the Americas, along with the Muscovy duck, guinea pig, llama, and alpaca (assuming that the latter two are separate species). The turkey was initially domesticated in Mesoamerica over 2000 years ago. There is evidence of domesticated turkeys in Mayan settlements in what is present day Guatemala (also see Chapter 1). This was outside the natural range of turkeys. As early as 1501, Spanish seamen took domesticated turkeys to Europe, where they were bred and sold. In the 1920s, there were breeding programs in the UK to improve turkeys. These improved turkeys were then imported to the

United States where they were crossed with native wild turkeys and then subject to selection and scientific breeding. Commercial turkeys predominantly use birds with white plumage.

Factoids, Myths, and Misunderstandings about Turkeys

Turkeys Come from Turkey—No!

There has been some confusion in the naming of the turkey. Spanish conquistadors took domesticated turkeys to Spain. These birds were bred and the offspring then traded to countries around the Mediterranean, including Turkey. In Europe, the turkey was confused with the guinea fowl (called a turkey-cock). Another mistake was in thinking that the guinea fowl came from Turkey when, in fact, it comes from West Africa!

Turkeys and Thanksgiving

The original turkeys for the Pilgrims' "Thanksgiving" celebration in 1621 were wild turkeys. There is a misperception about that first Thanksgiving. It was really a harvest feast with Thanksgiving being a day of prayer and fasting.

Species Name for Turkeys (*Meleagris gallopavo*)

Meleagris is derived from the mythological Greek hero Meleager. *Gallopavo* is derived from the Latin words *gallus* for male chicken and *pavo* for peacock. Again, a misidentification in the name!

Turkeys as the National Bird of the United States

According to the magazine *Smithsonian*, it is a myth that Benjamin Franklin wanted the turkey to be the national bird of the United States.

Christmas Goose (Later Christmas Turkey)

The now-classic story *A Christmas Carol* (1843) by Charles Dickens, featured poultry. Ebenezer Scrooge (with the Ghost of Christmas Present) visits his clerk, Bob Cratchit, and his family in a vision, as they are eating a small goose on Christmas Day. After a complete change of heart, Scrooge buys the prize turkey for the Cratchit family, including Tiny Tim.

Production of turkey meat is important globally (see Chapter 1), specifically in North America (predominantly the United States) with almost half of global production, Europe with over a third of global production, and South America with 12% of global production (Table 20.1). Among the nations with greatly increased production are the following in alphabetical order:

- Brazil has increased production from 0.09 million metric tons in 1996 to 0.29 in 2006 to 0.60 in 2016.
- Germany has increased from 0.21 million metric tons in 1996 to 0.38 in 2006 to 0.49 in 2016.
- The Netherlands has increased from 0.036 million metric tons in 1996 to 0.058 in 2006 to 0.061 in 2016.
- Poland has increased production from 0.040 million metric tons in 1996 to 0.060 in 2006 to 0.18 in 2016.

In 2017, the impact of the turkey industry in the United States alone was estimated to have produced 3.40 million metric tons (7.49 billion pounds) of turkey meat and provided 375,000 jobs, $21 billion in wages, $97 billion in economic activity, and $7.5 billion in government revenue. The top US states for turkey production are shown in Table 20.2.

A. Wild turkey in native grass in southern Iowa (Source: USDA Natural Resource Conservation Service)

B. Wild turkey showing male sexual display of the tail feathers. (Photo courtesy of David Gernant)

Figure 20.1 Wild turkeys. (A) Hen. (B) Tom displaying with tail feathers.

Table 20.1 Changes in the global production of turkey (in million metric tons).

Territory	2007	2017
Americas	**3.42**	**3.60**
North America	2.87	2.88
South America	0.53	0.70
Europe	**1.74**	**1.97**
Eastern	0.20	0.25
Northern	0.20	0.20
Southern	0.37	0.57
Western	0.97	0.95
World	**5.46**	**5.95**

Data from FAOStat.

Table 20.2 Top turkey producing states in the US in 2017.

State	Number of Turkeys in Million Head	State	Weight of Turkey in Billion lb (Million Metric Tons)
Minnesota	42.0	North Carolina	1.144 (0.52)
North Carolina	32.5	Minnesota	1.058 (0.48)
Arkansas	26.5	Indiana	0.792 (0.36)
Indiana	20.0	Missouri	0.624 (0.28)
Missouri	18.8	Arkansas	0.557 (0.25)

Data from the USDA.

20.2 Composition of Turkey Meat

Turkey is an important meat, being the fourth most consumed meat in the United States. This is related to price, cooked properties, and the perception of healthiness. Uncooked turkey is composed of 70% water, 19–22% protein, and 7–9% fat. Not only does skinless turkey meat have much less fat than pork and beef but there is also proportionately less saturated fatty acids.

Muscle and Meat

Protein makes up about 19% of turkey meat. The major proteins in turkey meat are the same broad categories as in the chicken (see Chapter 19). They include (1) myofibril proteins including actin, myosin, and tropomyosin, (2) sarcoplasmic soluble proteins such as myoglobin and the glycolytic enzymes, and (3) the stromal proteins including collagen (connective tissue) and mitochondria. Both the processing and further processing of turkeys are covered in some detail in Section 20.6.

20.3 The Biology of Turkey Production

It is frequently assumed that the biology of a turkey is identical to that of chickens and, indeed, wild birds. This assumption is broadly correct but there can be marked differences. It is reasonable to hypothesize that the same situation exists in both turkeys and chickens. The important thing is to then test to determine whether or not this is true. Examples of differences include (1) the presence of broodiness and its control by the hormone prolactin in commercial turkeys but not commercial chickens (although present in Bantam breeds of chickens); (2) greater photoperiodic control of reproduction; (3) differences in the ability to tolerate high temperatures; (4) differences in secondary sex characteristics (see Figure 20.2); and (5) differences in nutritional requirement.

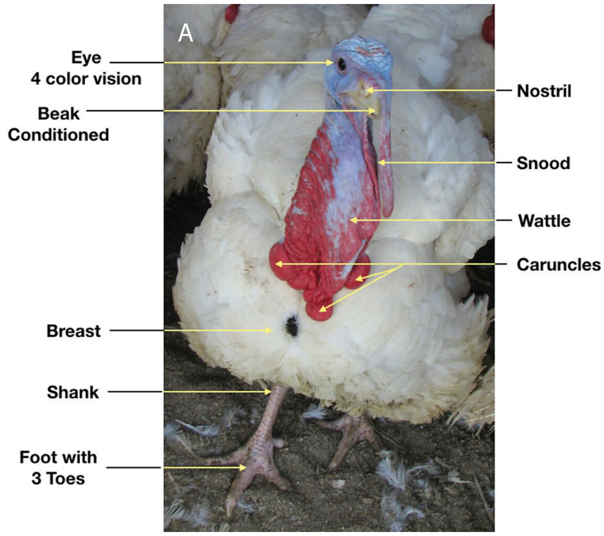
Like the situation with broiler chickens, the rapid growth rate of turkeys reflects superior genetics (intense selection for growth rate) and improved nutrition. This selection has also brought about marked differences between commercial domestic turkeys and wild turkeys. The overall biology of growth of meat is similar to that in the chicken (see Chapter 19).

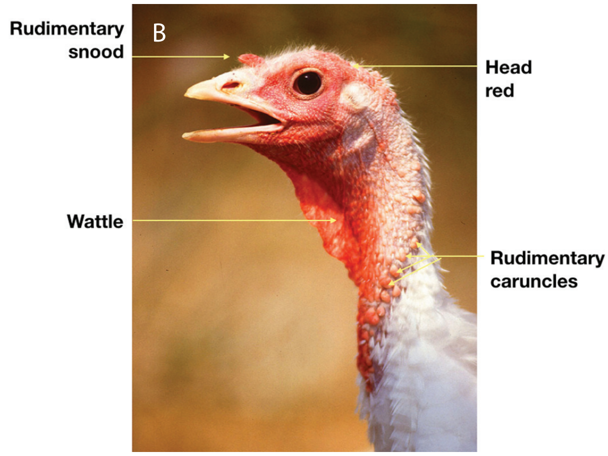
20.4 An Overview of Commercial Production of Turkeys

Today, turkey production and marketing is a highly efficient process, with turkey meat consumption being substantial throughout the year. For an overview of United States and world turkey production see Chapter 1. The leading companies in turkey producing and processing in the United States are shown in Table 20.3.

Business Aspects

With the increase in size and integration of turkey enterprises it is progressively more important to have





A. Tom turkey showing secondary sexual characteristics (blue or red wattle, blue head and blue or pink snood, bright red caruncles). (Courtesy of Gretta Irvin, Iowa Turkey Federation)

B. Hen turkey showing absence of male secondary sexual characteristics. (Source: USDA Agricultural Research Service. Photo by Scott Bauer)

Figure 20.2 Anatomy of a sexually mature male turkey compared to mature female.

Table 20.3 Largest turkey producing companies in the US in 2017.

1. Butterball
2. Jennie-O Turkey Store
3. Cargill Turkey and Cooked Meats
4. Farbest Foods
5. Tyson Foods
6. Perdue Farms
7. Virginia Poultry Growers Cooperative
8. Kraft Heinz
9. Michigan Turkey producers
10. West Liberty Farms

Data from WattAgNet.

excellent management of the business; effective husbandry, including recordkeeping (biosecurity measures in place; programs to assure bird health in place; mortality recorded daily, weekly and cumulative; water consumption; ventilation systems operating effectively; etc.); consumer confidence in the welfare of turkey production and the quality of turkey meat; and attractive new products.

Definitions

Productivity is the rate of output per unit of input. This can be stated as follows: productivity is the rate of output (say liveweight of turkeys) per unit of labor. Alternatively, productivity is the rate of output (say liveweight of turkeys) per unit of a turkey facility.

Productivity and efficiency of labor is critical to success (profitability) in turkey production. The more turkeys (more accurately—the more liveweight) raised per worker (productivity), the lower the production costs. Also the bigger the operation, the more feasible it is to automate. Greater productivity is a primary force increasing the number of turkeys per farm. Labor-saving equipment includes automatic feeding and watering systems.

Turkey Contracts

When turkeys are grown under contract, contractors generally provide poults, feed, and services, while producers provide labor and facilities. Types of contracts include **profit sharing** and **base pay and bonuses**. Under profit sharing, the contractor provides inputs (poults, feed, services, medication, etc.) on an at-cost basis. The cost of these inputs, plus hauling charges, is first deducted from the gross receipts from the sale of turkeys. Fixed percentages of the remaining receipts are distributed to the contractor and to the grower. Under base pay and bonuses, the contractor provides poults, feed, medication, and services, and pays the grower based on the number of weeks to market or live weight, plus bonuses for livability, feed conversion, and grade yield.

Costs and Returns

Costs and returns in the turkey business are essential to determining how well an established enterprise is doing and deciding whether to enter the business or to expand. Returns of turkey production differ from year to year and from area to area. The differences in returns and production costs between growers can account for the success or failure of the enterprise. This emphasizes the need for adopting a series of goals to produce more turkeys/turkey live weight for less than the competition (see Tables 20.4 and 20.5). Moreover, there is a need for flexibility when responding to the market nimbly.

Costs

Below are the approximate costs of turkey production (in US$).

- Feed costs about $0.35 per lb ($0.77 per kg) but a variable cost depending on the price of feed ingredients.
- Other costs (poults, equipment, buildings, labor) and profit are $0.11 per lb ($0.22 per kg).
- Processing turkey costs $0.19 per lb ($0.42 per kg).

Tables 20.4 and 20.5 summarize goals for growth and feed efficiency for Nicholas Select turkeys.

It is important to strive to reduce costs. Costs can always be lowered but that does not mean corners can be cut! Start with the highest cost item. Because feed represents about two-thirds the cost of production, any change in feed cost or efficiency will dramatically influence the cost of production. Feed costs can be decreased by locating the turkey operation in an area where major feed ingredients are produced, using improved feed formulations, selecting efficient turkey strains, and reducing mortality (high mortality increases feed consumption per unit weight of turkey produced).

Turkey growers buy or receive 5–10% more poults than they anticipate raising to account for mortality. Lowering mortality results can result in a savings in the cost of poults and/or greater production.

Approaches to reduce labor costs and increase productivity include respect between management and labor (including a career ladder where possible), provision of expectations, incentives, having clear standard operating procedures (SOPs), good training, superior supervision, and automation. The turkey producer should also be aware that facilities and equipment change rapidly. It is important that growers visit successful operations and trade shows to view effective approaches and new technologies.

Table 20.4 Production goals for growth by Nicholas Select turkeys.

Age (in Weeks)	Female wt in kg (lb)	Male wt in kg (lb)
1	0.15 (0.34)	0.16 (0.34)
3	0.64 (1.4)	0.71 (1.6)
6	2.1 (4.7)	2.9 (6.5)
10	5.4 (12.0)	7.9 (17.4)
15	10.4 (23.0)	15.4 (33.9)
20	14.8 (32.6)	22.6 (49.8)
22	—	25.2 (55.5)

Based on Aviagen Turkeys.

Table 20.5 Production goals for feed: gain by Nicholas Select turkeys.

Age (in Weeks)	Female	Male
1	1.19	1.04
3	1.30	1.16
6	1.50	1.37
10	1.80	1.61
15	2.18	1.98
20	2.68	2.43
22	—	2.63

Based on Aviagen Turkeys.

20.5 Overall Considerations of Turkey Production

Overview

Management is the key to success in the turkey business. The geneticist can lift the potential of production; the nutritionist can formulate a feed that can reach this potential; but without proper management, the turkey producer will never get there. Management can make or break a turkey enterprise. Turkey operations respond favorably to good management.

Turkey producers have specific goals; for example, lowering incubated egg infertility to < 5%, lowering embryonic deaths to < 5%, lowering poult mortality to < 4%, and < 2.2 and < 2.4 units of feed per unit weight for turkey hen and tom growth (see Table 20.5).

Selecting Poults

Start with sexed poults with high genetic quality that are from a hatchery with breeder flocks pullorum-typhoid clean and PPLO tested. The sexed poults should be raised separately.

Separating the Sexes

The sex of day-old poults may be determined by examining the vent. Sexing is performed at hatcheries. The advantages of raising the sexes separately include a reduction of injuries to the hens, hens can be marketed at an earlier age than the toms, and sex-separated flocks can be fed different diets and thus be more efficient. Some producers buy straight-run poults and then separate the sexes at 12 to 14 weeks of age.

Brooding and Growing

The successful brooding of poults is critical to turkey production. It depends upon satisfying all the requirements of the young birds at this early stage in their development. Turkeys are brooded in brooder houses and then moved at 4 to 6 weeks old to grower houses. Brooding is considered in more detail in Section 20.6.

Genetics

Although raising turkeys for market is the largest phase of the turkey industry, the breeding of turkeys is the foundation. Primary breeders provide turkey poults and parent breeding stock while retaining grandparent, great-grandparent, and pedigree lines (also see Chapter 4). The hatchery is a critical component of a primary breeder, hatching eggs from grandparent, great-grandparent, and pedigree lines and possibly—at a separate location—eggs from parent lines.

Turkey selection has involved mass selection; specific breeding index characteristics including growth rate, feed efficiency, carcass yield and breast yield, and livability; BLUP (best linear unbiased prediction), and DNA markers for marker-assisted selection.

Primary Breeders

The primary or foundation breeder follows an intensive genetic program designed to achieve increased fertility, hatchability, and livability of poults; uniformity of growth; better feed conversion; a shortening in the number of weeks to market; and more uniformity in type, size, and weight. The major primary breeders of turkeys in the world are the following:

- Aviagen includes the brands B.U.T. (formerly British United Turkeys) and Nicholas, together with heritage birds from Valley of the Moon (VOM). Aviagen is part of the EW Group GmbH, a holding company based in Visbek, Niedersachsen (Lower Saxony), Germany.
- Hybrid Turkeys includes alternative/heritage products: Orlopp Bronze, Artisan Gold, and MiniCLASSIC. Hybrid Turkeys is part of Hendrix Genetics.

Breeds and varieties are considered in Appendix I. The Broad-Breasted Bronze turkey was originally developed in England. The breed was imported into North America around 1930. Within a few years after its introduction, it became the most widely grown of all varieties. It was used to produce the Broad-Breasted White and the Beltsville Small White.

The multiplier works very closely with the breeder (same company) and multiplies turkeys from a definite brand (line or strain) or variety from the breeder. Production of poults is considered in Section 20.9.

Turkey Health and Disease

Turkeys seem to be more susceptible to pathogenic disease and require a higher level of management than chickens. One severe outbreak of a disease is usually all that is needed to turn a flock from a profit to a loss. Many diseases are at least partly under the control of the turkey producer. They may be controlled or prevented with biosecurity, including good plans and well-trained employees (see Chapter 16); by vaccination; with professional services from poultry veterinarians and pathology laboratories; and by proper management, such as "all-in, all-out" systems. The number of turkeys raised in "all-in, all-out" systems rose from 39.3% in 2008 to 59.8% in 2016 (Bailey and Clark, 2017).

Pathogens can be spread from bird to bird or from vectors (see Chapter 11 for details). Of the common pathogens, only the *Salmonellas*, the paracolons, and the *Mycoplasmas* are transmissible vertically through the egg.

Biosecurity

Biosecurity is so important to the success of turkey producers and to the entire community. Biosecu-

TEXTBOX 20A

A Deeper Dive: Genetics and Immune Responses in Turkeys

Domestication and selection has been accompanied by changes in the immune responses in turkeys. This is based on comparisons between wild turkeys and commercial domestic turkeys. Heterophils from wild turkeys showed greater oxidative burst (OXB) responses to both phorbol A-myristate-13-acetate and *Salmonella enteritidis* or opsonized *Salmonella enteritidis* (Genovese et al., 2006; 2007). There is additional evidence that selection in modern turkeys has resulted in some shifts in the immune system in addition to enhancing growth rates and feed efficiency (see Textbox 20A Table 1).

Aviagen parental (purebred) genetic turkey lines show some marked differences in immune responses. Peripheral blood mononuclear cells are cells with round nuclei and include lymphocytes (T cells, B cells, NK cells) and monocytes. These cells show large differences in their ability to kill *Salmonella Heidelberg* in vitro depending on both sex and genetic lines (Potter et al., 2016).

Textbox 20A Table 1 Effects of selection on growth, feed efficiency, and immune parameters.[1]

Parameter	Random-Bred "1966" Type Turkey	Commercial Turkey
Body weight at 8 weeks (kg)		
Males	(2.5)	↑↑ (4.8)
Females	(2.0)	↑↑ (4.1)
Body weight at 20 weeks (kg)		
Males	(7.9)	↑↑ (15.5)
Females	(5.8)	↑↑ (12.4)
Feed efficiency at 20 weeks (kg)		
Males	(2.93)	↓ (2.64)
Females	(2.94)	↓ (2.65)
Bursa Fabricius weight (% of body weight)	(0.35)	↑↑ (0.65)
Antibody response	→	→
Lymphoblastic response	→	→

[1] Based on feeding 2003 diet.

Data from Cheema et al., 2007; Havenstein et al., 2007.

rity encompasses a biosecurity plan (written and implemented), training for all personnel, appropriate changes of clothing and boots, sanitation and disinfection, ensuring lack of direct and indirect contact between turkeys and either wild birds or poultry on neighboring facilities, restriction on visitors to the minimum, disposal of mortalities, and emergency plans.

Vaccinations

Vaccines help build resistance to specific diseases. No vaccine is completely effective. There may be adverse reactions or lack of effectiveness. Vaccination (by addition to the drinking water) is performed in the absence of chlorine, antibiotics, disinfectants, and other additives in the water. Vaccine producers are responsible for producing safe, potent, and effective vaccines. Users also have responsibilities, such as ensuring that vaccines are refrigerated or stored properly, used within the expiration date, mixed according to directions, applied to birds that are in good health when vaccinated, and administered according to the directions. The vaccination program should be based upon the requirements of the flock and the advice of turkey veterinarians.

All turkeys should receive vaccination for Newcastle disease since the disease could cause serious effects, such as disruption of egg production. A common practice is to vaccinate in the drinking water with a B1 type of Newcastle disease vaccine. Other possibilities include injection of LaSota Strain and a tissue culture strain. In the United States, the usual vaccinations for turkeys are for Newcastle disease (at the hatchery), with booster shot(s) if needed, and for hemorrhagic enteritis (at 4 weeks old). Possible vaccinations for tur-

Textbox 20B

A Deeper Dive: Diseases in Turkeys

Textbox 20B Table 1 summarizes the top issues for the health of turkeys based on surveying turkey veterinary professionals. What is clear is that while there are diseases caused by bacterial, viral, and single-celled organisms impacting turkey production, there are other issues.

Other issues reported include poult enteritis, tibial dyschondroplasia, osteomyelitis, protozoal enteritis, heat stress, roundworms (*Ascaridia dissimilis*), breast blisters, breast buttons, and Newcastle disease virus (NDV), together with the emerging disease turkey reovirus digital flexor tendon rupture (TR-DFTR). The major concern is the lack of approved drugs. There is no drug that is effective against blackhead. Moreover, *Ornothobacterium rhinotracheale* (ORT) develops an antibiotic resistance.

Textbox 20B Table 1 Diseases and issues in turkeys.

Ranking	Disease/Issue
1	Lack of approved, efficacious drugs.
2	Colibacillosis (Colisepticemia). Infectious agent: bacterium *Escherichia coli*.
3	Clostridial Dermatitis (Cellulitis). Infectious agent: bacteria *Clostridium septicum*, *C. perfringens* type A, or *C. sordelli*.
4	Ornithobacterium infection. Infectious agent: bacterium *Ornithobacterium rhinotracheale* (ORT). There can be concurrent turkey rhinotracheitis (TRT) virus infection.
5	Leg Problems
6	*Salmonella*
6	Late Mortality
8	Turkey Coryza. Infectious agent: bacterium *Bordetella avium*.
8	Blackhead (Histomoniasis). Infectious agent: protozoan.
10	Avian Influenza (AI)[1]
10	Cannibalism
12	Cholera
12	Coccidiosis

[1]Either low pathogenic (LP) or highly pathogenic (HP)

Data from Bailey and Clark, 2017.

keys can be used for *Bordetella avium* (against turkey coryza); coccidiosis; hemorrhagic enteritis, when maternal immunity has declined at about 2 weeks of age; and fowl cholera. There should be caution so that only healthy birds are vaccinated.

Professional Services from Poultry Veterinarians and Pathology Laboratories

Detection of Disease

A sign of disease is reduced feed and/or water consumption. In addition, birds may be nervous or chirping or moving rapidly around or droopy or listless. Coughing and sneezing indicate respiratory infections; abnormal droppings suggest intestinal disorders. Young poults may crowd together and seem to be cold even though heat is available. These warning signals indicate the need to check the birds' health. When sick turkeys are detected, they should be isolated.

Diagnosis

Once sickness is indicated, an accurate diagnosis by a veterinarian should be obtained as soon as possible. This is to know what is wrong, to treat the flock properly, and to prevent further losses. Dead birds should be subject to necropsy.

Examples of Bacterial Infections in Turkeys

Pneumonia/respiratory diseases are caused by *Ornothobacterium rhinotracheale* (ORT) and lead to depression in growth and increased mortality in commercial turkeys, and reduced egg production in turkey breeders. Infection with this Gram-negative bacteria can be overcome with antibiotic treatment.

Infectious sinusitis is caused by the mycoplasma bacteria *Mycoplasma gallisepticum* (MG). There may be secondary infections from *E. coli* or *Pasteurella multocida* (fowl cholera). Condemnations can reach 70%. While vaccines are not available, infected birds can be treated with the antibiotic tylosin. Following a withdrawal period, turkeys can be marketed. It is then critically important to ensure that the premises are completely depopulated and thoroughly cleaned as the pathogen is found in the excreta.

Parasites in Turkeys

Ectoparasites

The most common external parasite is the fowl mite. This very small, gray mite can move quite rapidly. Fowl mites live mostly in the tail feathers and in the fluff feathers at the rear of the keel. Infestations can build up quickly in a flock. The insemination crew should report mites.

Endoparasites

Roundworms are a relatively common internal parasite. Roundworm eggs are spread by contaminated litter or soil. It is particularly important due to the spread of blackhead. Regular worming reduces the problem to low levels. Single-celled parasites include *Histomonas meleagridis* and coccidia.

Blackhead disease (Histomonas meleagridis)

Blackhead disease is caused by the single-celled parasite *Histomonas meleagridis*. It can be transmitted by the cecal nematode worm *Heterakis gallinarum*. It can remain viable in the soil. In turkeys, catastrophic mortality rates are reported being between 80 and 100%. The arsenical nitarsone was employed in the past to protect against *Histomonas meleagridis*, however this is no longer permitted in the US by the Food and Drug Administration (FDA). Control of blackhead disease requires quarantine, particularly excluding contact with chickens; excluding migrating birds; and sanitation.

Antibiotics and Coccidiostats

Antibiotics and coccidiostats are widely used in the turkey industry for the prevention of disease and as growth stimulants. Turkey producers may (1) dip the hatching eggs in antibiotics to control *Arizonosis* and *Mycoplasma* infection, (2) start the poult on a coccidiostat and an antibiotic, (3) give increased drug treatment at times of stress, (4) and use drugs to treat specific infectious diseases, such as fowl cholera.

However, some coccidiostats (e.g., ionophores) cannot be for antibiotic-free turkeys. It is recommended that anticoccidial drugs like amprolium, Clinicox®, Stenerol®, and Zoamix® are used in a rotation together with vaccination.

Drugs Approved for Turkeys

Drugs approved for turkeys in the US include the therapeutic drugs amprolium, bacitracin methylene disalicylate, chlortetracycline, clopidol, diclazuril, fenbendazole, halofuginone, and lasalocid; and the subtherapeutic drugs bacitracin zinc, bacitracin methylene disalicylate, bambermycin, chlortetracyclin, neomycin + oxytetracycline, oxytetracycline, ractopamine, monensin, neomycin + oxytetracycline, and sulfadimethoxine + ormetoprim.

Abnormalities and Injuries

The following are abnormalities and injuries found in turkeys:

- **Breast Blisters/Calluses** may be caused by irritation of the skin over the breastbone. They can cause serious losses due to downgrading of the carcass.
- **Cannibalism and feather-picking** is seen in the growing period. There can be growth retardation, the potential for further injury (flesh picking), and increased mortality. Management practices that reduce feather-picking include avoiding overcrowding and feeding an adequate diet of pellets rather than loose mash.
- **Rickets and tibial abnormalities** have severe consequences to growth and mortality. Remedies include feeding a diet with optimal calcium (1.5%), phosphorus (0.75%), and vitamin D (2,000 IU/lb feed or 4,500 IU/kg feed); ensuring that feed is not contaminated by fungal toxins (mycotoxins); and reducing animal fat in the feed.

TEXTBOX 20C

A Deeper Dive: The Impact of Pecking on Mortality in Turkeys

In a study of commercial tom turkeys in grower facilities, 5.24% were mortalities/culls, of which 59% were due to severe pecking. Pecking is first seen at about 6 weeks old in tom turkeys. Mortalities/culls and severe pecking-related mortalities/culls are influenced by housing and are markedly lower in controlled environment housing (Duggan et al., 2014). This is assumed to be due to lighting.

Pest Control

Rodent Control

Approaches to control rats and mice include exclusion, poisons, and trapping.

Sparrow and Other Birds

Approaches to control house sparrows include exclusion, repellants (sound or tactile), poisons, trapping (e.g., funnel type traps, drop in traps, or triggered traps or snares), shooting, nest destruction, and predators (e.g., cats).

Darkling Beetles

Darkling beetles can proliferate in the litter and spread diseases. It is critically important that these are controlled. This can be accomplished using insecticides at the manufacturers' recommended dosage. Lower dosages can lead to a build-up in resistance to the insecticide. Rotate the four types of insecticides: organophosphate (with added citric acid), pyrethroid (with added citric acid), spinosad (with added ammonia), and neonicotinoid insecticide (e.g., imidacloprid).

Housing

Vegetation around either brooder or grower houses should be kept low to allow airflow and facilitate rodent control by allowing inspection for holes, etc. Employ shade trees around the barns to reduce radiant energy. If natural ventilation is to be used, it is suggested that barns be built on east-west ridge lines so that wind can provide ventilation. Construct the turkey houses with concrete foundations, generally earthen floors, tight-fitting doors and windows, and ensure all openings are covered by 3/4-in. (1.8 cm) (or smaller) mesh wire. It is advisable to raise turkeys away from chickens to reduce transmission of blackhead; this being caused by a single-celled organism (*Histomonas meleagridis*) with cecal worms being an intermediate host.

Litter

Litter is 4 to 6 inches (10 to 12.5 cm) deep and consists of soft wood shavings or straw (wheat straw, beardless barley straw, peat moss, shredded cane, rice hulls, and processed flax straw). With the addition of excreta, there is some natural composting. Litter should be kept dry and clean by adding to it when necessary. Accumulations of droppings and wet litter should be removed as they are linked to the development of leg problems and mold. Adequate ventilation is the key to good litter management and preventing the buildup of pathogens.

Temperature Control and Ventilation

Ventilation is always important with either natural ventilation or a well-designed system of fans and intakes (tunnel ventilation houses are becoming more popular).

20.6 Meat Turkeys and Their Management

Overview

Poults are transported from the hatchery (see Section 20.9) to the brooder houses (brooder farms) (see Figure 20.3). At about 4–6 weeks old, they are moved to grower houses or grow-out facilities. The principle advantage of moving birds from brooder to grower houses is to assure male and female poults are raised separately.

Brooding

Young poults must be kept warm and dry. Hover brooders are used to produce a warm environment. Radiant type brooders are very effective in warming the litter and assuring bird comfort.

Prior to Brooding

The house must be ready to receive the poults (see Figures 20.3 and 20.4). It is critical to clean and sanitize the grower house, feeders, waterers, and water lines. There should be clean, dry litter. It is advantageous to have rough-surfaced and absorbent paper covering the litter at least under the feeders. This paper serves for firmer footing (reducing the development of leg problems) and to prevent young poults from eating enough litter to clog their digestive tract. There should be some feed on the paper close by the feeders. Feeders, waterers and all equipment must be working. The brooding temperature should be established in the house at least 24 hours before the poults are set to arrive. See Table 20.6 for recommended brooding temperatures.

Brooding can be accomplished with (1) whole-house brooding or (2) brooding within brooder guards or brooder rings (see Figure 20.5). Brooder guards are set up to protect the poults from drafts and keep them close to the brooder heat. Young poults must be kept warm and dry. Table 20.6 summarizes recommended brooding temperatures. The guard prevents crowding and smothering in the corners of the house. Brooder guards have to be in place ready for the arrival of the poults.

Once the Poults Arrive

One of the first items of husbandry is getting poults to eat and drink. It is critical to inspect the

Figure 20.3 Placement of poults for brooding. This follows thorough cleaning, setting up for brooding, and checking on all equipment. (Courtesy Gretta Irwin, Iowa Turkey Federation)

Figure 20.4 Turkey poults brooding. One of the factors critical to the success of a turkey operation is brooding. (Courtesy of Gretta Irvin, Iowa Turkey Federation)

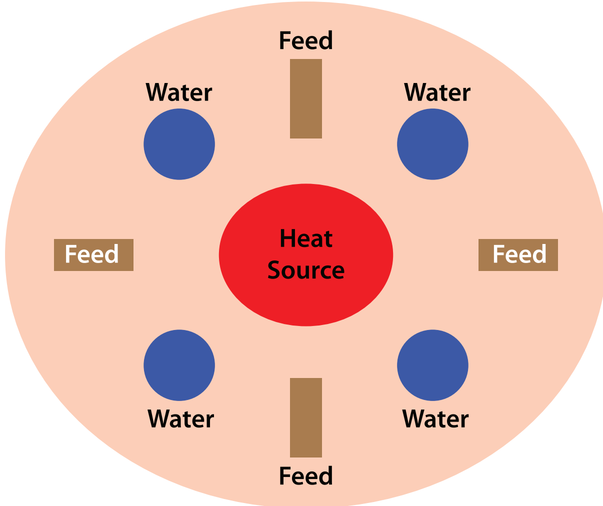


Figure 20.5 Schematic of single brooder ring for turkey poults. The single brooder ring should be a cardboard brooder guard 30–45 cm high (12–18 inches) as a ring with a diameter of 4–5 meters (12–15 feet). The ring can contain 350 male or 400 female poults for 5–7 days. There should be 4 feeders, each 120 cm (48 inches) and 4 waterers per ring. (Adapted from Aviagen Turkey Management Guidelines)

Table 20.6 Brooding temperatures for turkeys of difference ages or sexes.

Age	Sex	Conventional brooding °F (°C)	Large ring or whole house brooding °F (°C)
Day 1	M+F	86 (30)	94 (34)
Week 1	M+F	83 (28)	88 (31)
Week 3	M+F	77 (25)	82 (28)

Based on Aviagen Turkeys.

poults (daily and initially more frequently) for temperature (thermostat and poult behavior—are they huddling or avoiding drafts?), crop fill (are they eating?), mortalities (daily, cumulative), and water consumption (a very useful indicator of bird health). Heating is by brooders (hover or radiant) fueled by gas (natural or propane), oil, or electricity.

End of Brooding

Birds are allowed greater space. Floor papers and brooding guards are removed after about 7 days. However, the removal of the brooding guards can be delayed in cold weather.

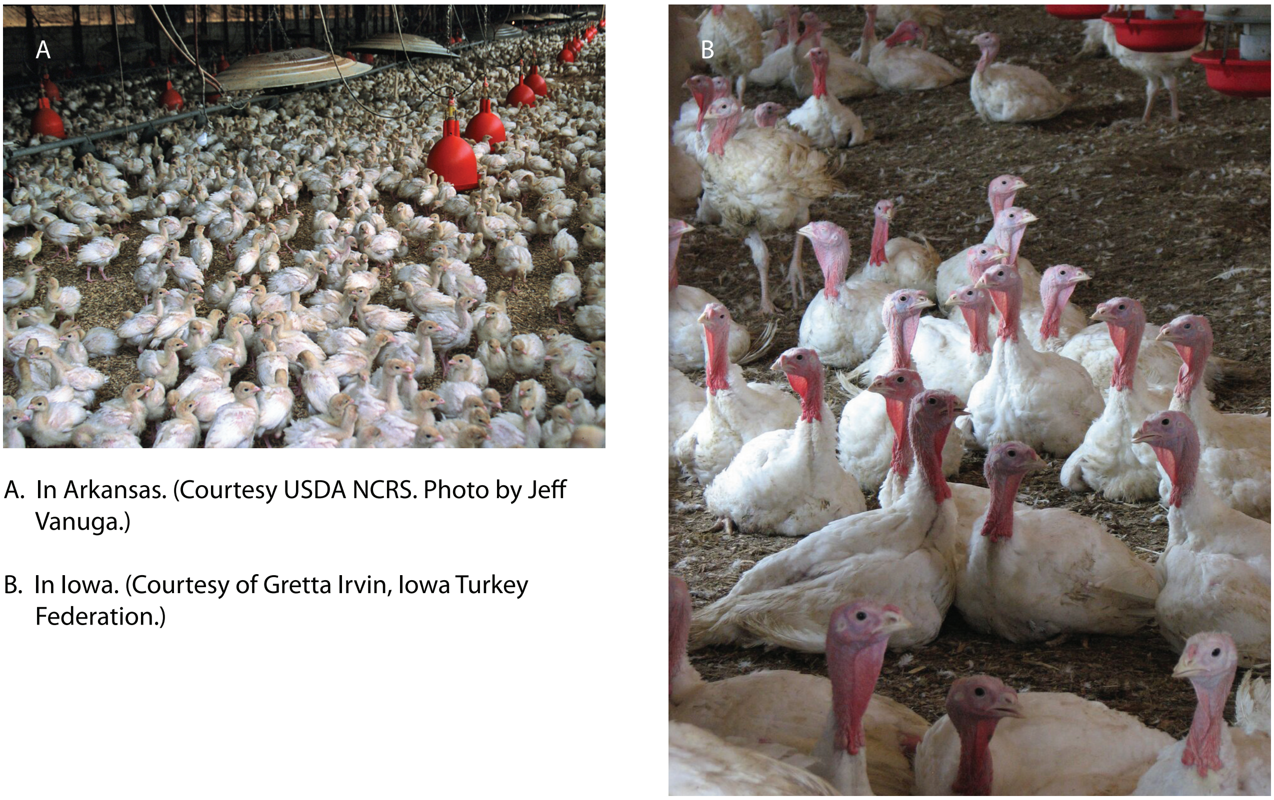
Grow-Out Housing

Rearing Turkeys

Turkey houses can be either (1) controlled environment housing with fan ventilation to achieve the desired temperature and humidity or (2) curtain-sided housing (with natural ventilation). Barns can be either one or two stories but are usually a single story. Turkey

Figure 20.6 Turkey poults being raised on litter (wood chips) in a single barn. After use, spent litter can be composted and then used as fertilizer. (Source: USDA NCRS, photo by Jeff Vanuga)

Figure 20.8 Turkeys being raised in barns with large open windows to aid ventilation and temperature control. Blinds are open. These can be closed to control the day length. (Source: USDA NCRS; photo by Bob Nichols)



A. In Arkansas. (Courtesy USDA NCRS. Photo by Jeff Vanuga.)

B. In Iowa. (Courtesy of Gretta Irvin, Iowa Turkey Federation.)

Figure 20.7 Growing turkeys on litter.

grow-out houses can accommodate between about 5,000 and 10,000 depending on their size. The number of finisher turkeys raised in tunnel-ventilated houses (see Chapter 17) in the US rose from 14.5% in 2008 to 30.3% in 2016 (Bailey and Clark, 2017).

Brooder and Grower Houses

Widths usually varies from 24 to 40 ft (7.5 to 12 m), and length from 100 ft up to 600 ft (30 to 180 m). Clear-span, rigid-frame, gable-roof houses 40 ft (12 m) wide and 300 ft (100 m) long are popular. For raising turkeys in cold-weather environments, insulation of sidewalls and ceiling is needed. There may be partitions at intervals in long houses with 1,000 to 1,500 birds per pen. This limits stampedes and reduces disease outbreak. If brooder and grower houses are on different premises, the birds need to be transported to the grow-out farm. If they are close, they can be moved via a passage or walkway.

Feeders

Either large-capacity metal hopper-type or automated feeders should be used. Feeders are distributed so feed is readily available to all birds.

Waterers

Nipple drinkers are used in brooder houses together with supplementary drinkers. Bell and other types of large drinkers are used in grower houses.

Ventilation

Mechanical ventilation is desirable in all turkey houses, especially in those 40 ft (12 m) or more in width. Without ventilation, there are problems with high temperatures together with excess humidity and carbon dioxide from the birds and the brooders.

Lighting

For the first two weeks of brooding in all types of houses, the room should be well lighted day at 10 to 15 foot-candles (100–150 lux) and night (at least 4 hours). After two weeks, only dim light at 0.5 foot-candle (5 lux) is needed at night, none in the daytime. In windowless houses, the light intensity can be reduced gradually to about 1 foot-candle (10 lux) during the 16-hour day.

Stocking Density/Floor Space

The recommended stocking density for growing poults is summarized in Table 20.7. In naturally ventilated brooder houses, allow at least 25% more space per bird.

Table 20.7 Stocking densities for Nicholas Select turkeys.

Age (in Weeks)	Female	Male
	# per m^2 (# per ft^2)	
0–6	11 (1.0)	11 (1.0)
7–12	5.5 (0.5)	4.0–4.5 (0.37–0.40)
13–16	5.5 (0.5)	3.0–3.5 (0.28–0.30)
> 17	4.5 (0.4)	2.5–3.0 (0.23–0.28)
	m^2 per bird (ft^2 per bird)	
0–6	0.09 (1.0)	0.09 (1.0)
7–12	0.19 (2.0)	0.19–0.23 (2.0–2.5)
13–16	0.21 (2.3)	0.23–0.28 (2.5–3.0)
> 17	0.23 (2.5)	0.28–0.37 (3.0–4.0)

Based on Aviagen Turkeys.

Nutrition

Nutrition and Feeding

Nutrition is critically important. Feed is about two-thirds of the total cost of producing turkeys. Feeding turkeys for maximum profit requires the use of knowledge of nutrition and a judicious assessment of prevailing feed prices. A successful program must provide the turkeys with the required nutrients in the amounts and proportions to satisfy their needs and maximize profit. The basic nutrient categories are proteins, carbohydrates, fats, minerals, vitamins, and water. Distributed within these categories are some 40 separate nutrients that turkeys require (also see Chapters 6 and 7). With improved genetics, together with nutrition and management, feed conversion and growth rate of turkeys are constantly improving. The nutritional requirements for growing turkeys are shown in Table 20.8. Commercial turkey producers link aggression in turkeys with nutrition such as low sodium and deficiencies in either tryptophan or methionine in the feed.

Water Intake

Table 20.9 summarizes the expected water consumption and the influence of house temperature on water consumption. The quality of water for turkeys is important. Testing, filtration, sanitation, and softening is frequently required for noncity water (see Chapter 17).

Table 20.8 Nutritional requirements for Nicholas turkeys.

Age (in Weeks)	Energy—kcal per kg	Protein % (Lysine %)	Calcium %
0–4	3020	26–28 (1.82)	1.49
4–6	3100	24–26 (1.62)	1.38
Toms: 6–9 Hens: 6–8	3150	23–25 (1.47)	1.24
Toms: 9–12 Hens: 8–10	3250	22–22 (1.31)	1.14
Toms: 12–14 Hens: 10–12	3300	18–20 (1.17)	1.0
Toms: 14–16 Hens: 12–14	3350	16–18 (1.09)	1.01
Toms: 16–18 Hens: 14–16	3450	15–17 (1.01)	0.93
Toms: 18–21 Hens: 16–18	3500	14–16 (0.92)	0.82

Based on Aviagen Turkeys.

Table 20.9 Water consumption by growing turkeys as influenced by age and environmental temperatures.

	Water Consumption as Liters per 1000 Birds (Gallons per 1000 Birds)		
Age (Weeks)	< 75°F (< 24°C)	75–90°F (24–32°C)	> 90°F (> 32°C)
1	40 (11)	42 (11)	42 (11)
3	131 (35)	147 (39)	167 (44)
6	282 (75)	338 (89)	409 (108)
12	723 (191)	831 (219)	994 (263)
18	807 (213)	1029 (272)	1161 (307)

Based on Aviagen Turkeys.

Temperature

Recommended temperatures for growing turkeys are summarized in Table 20.10. Hot weather depresses growth rate while cold weather lowers feed efficiency.

Heat stress is found with temperatures above 75°F (24°C). The following are approaches to reduce heat problems.

1. **Foggers/misters** reduce temperature in a poultry house by employing the latent heat of vaporization with heat absorbed leading to evaporation.

Table 20.10 Target room temperatures for turkeys of difference ages or sexes.

Age (Weeks)	Sex	Conventional Brooding °F (°C)
3	M+F	77 (25)
6	M+F	70 (21)
10	M+F	62 (17)
13+	Females	58 (14)
13	Males	56 (13)
14+	Males	55 (13)

Based on Aviagen Turkeys.

Latent heat of vaporization of water =
2.26 kJ per g (0.54 kCal per g)

Smaller droplets have a higher surface area to volume and hence evaporation will be quicker. With larger droplets, there is the risk of wet litter.

2. **Cooling pads** reduce temperatures again using evaporation. In this case, air is drawn across wet cellulose panels.
3. **Ventilation in tunnel houses** provides a light breeze of 4 miles (2.4 km) per hour decreasing the effective temperature by about 12°F to 15°F (7°C) (see Chapter 17).

Handling Practices

Beak conditioning: Poults should be beak trimmed (only the tip of the beak removed) to control feather-picking. This is done either by the hatchery at 1 day old or at 3 to 5 weeks old.

Catching turkeys: For catching turkeys, a darkened room is best. In the dark or semidarkness, turkeys can be picked up with both legs without confusion or injury. Portable catching chutes, preferably with a conveyor, can be used for catching and loading range turkeys.

20.7 Turkey Processing, Further Processing, and Marketing

Marketing of Turkey Meat

Turkey meat is marketed as (1) young turkeys (sex not specified); (2) young hens between 10–16 weeks old with dressed weights of 3.64–7.27 kg (8–16 lb); (3) young toms 16 weeks old and older with a dressed

TEXTBOX 20D

National Turkey Federation Animal Welfare Guidelines

Animal Welfare

- Management must be committed to animal welfare with a designated person/group responsible for animal welfare.
- Animal Abuse Reporting: There must be a process for employees and contract growers reporting "abuse or welfare concerns".
- Acts of willful abuse: If willful abuse is observed during an audit, this results in automatic failure.
- Poultry Welfare Training and Documentation: Employees and contractees must attend annual training programs covering at least the following topics: "General Health and Welfare" and "Bird Handling."

Biosecurity

It is essential to have a comprehensive biosecurity program encompassing disinfection, pest and insect control, sanitation, and visitors.

Bird Health and Comfort

- Access to feed and water
- Adequate nutrition
- Feed and water withdrawal not to exceed 12 hours prior to transportation
- Inspection/recordkeeping
- Lighting program - minimum of 4 hours darkness per day
- Protocol to treat lesions and skin tears
- Satisfactory litter moisture
- Vaccination program
- Ventilation
- Veterinary care

Emergency Response Plan

Written plan for emergencies including natural disasters and utility outages. There should be a system to continue ventilation in a power outage.

Training for Poultry Welfare

All employees and contractees must attend annual training programs covering at least "General Health and Welfare" and "Bird Handling." There should be training for all people performing euthanasia and beak conditioning.

Auditor Guidelines

- Pest control: verified pest control program
- Litter moisture: adequate.
- Breeder roaming space: sufficient roaming space.
- Flock Evaluation Scoring: inspect 100 birds. One bird showing problems is minus 3 points, two birds showing problems is minus 6 points, etc.
- Recovery pen for sick or injured turkeys: present.
- Bird handling: observed.

weight of 7.27–10.91 kg (16–24 lb); (4) young toms with a dressed weight of about 12.5 kg (27.5 lb); and (5) mature hens and toms (equivalent to spent hen in Chapter 18). These can be used in turkey products such as canned soups and stews. The USDA classes immature turkeys (male or female) of less than 12 weeks old as fryer-roaster turkeys.

The dressing percentage for broiler turkeys is about 77%. Table 20.11 summarizes the composition of turkey. It is clear that turkey is a high protein low-fat meat.

Most producers market their birds through integrated firms, processors, or cooperative organizations. The turkeys are collected and trucked to processing plants. Some turkey growers sell their turkeys directly to consumers or to local retail dealers. These growers may have their own processing and even freezing facilities.

Until the 1960s, fresh and frozen turkey was readily available only around the Thanksgiving and Christmas holiday season. Today, turkey is available year-round in the United States. About 30% of the per capita consumption of turkey meat still occurs at Thanksgiving and Christmas in the US with almost 90% of Americans consuming turkey at Thanksgiving and about 40% at Christmas (see Figure 20.9). The remaining sales are distributed fairly equally throughout the rest of the year. Turkeys are the most common meat in the family Christmas dinner in Canada and the UK.

There is a strong market for further processed turkey meat. Examples include sliced turkey (this being an important component in sandwiches) and the consumption of roast or smoked turkey drumsticks, for instance at state fairs and other outdoor parks.

Table 20.11 Nutrient composition (per 100 g) in turkey (cooked).

Type of Turkey	Protein	Fat	Calories
Roast (whole)	26.6	14.4	244
Roast (breast in skin)	28.7	7.4	189
Roast (white meat)	30.1	2.1	147
Tenders (fingers)	25.0	1.6	112

Figure 20.9 Roast turkey is an example of turkey meat we consume. It is a traditional dish for holidays such as Thanksgiving in the United States and Christmas in Great Britain. (Source: Brent Hofacker/Shutterstock)

Disney and Turkey Drumsticks

Turkey drumsticks are a popular item at Disney theme parks (e.g., Disneyland, Disney World). Over 1.5 million are sold each year. They weigh 1.5 lb (0.68 kg), contain 937 calories (calculated from USDA composition), and have 203 grams of protein and 14 grams of fat.

Slaughtering and Processing

The methods for slaughtering and processing turkeys are similar to that for chickens (see Chapter 19). Turkeys can be slaughtered following Islamic or Jewish religious laws, respectively, Halal and Kosher turkey (for details see Chapter 19). Most turkeys are now processed in plants that process turkeys only. The usual steps in processing follow.

1. **Suspended by legs.** The live turkey is manually placed into the shackles and suspended by the legs.
2. **Stunning.** An electric stunner is used to assure humane slaughter. This also prevents struggling and facilitates relaxation of the muscles that hold the feathers. Controlled atmosphere stunning is being employed by some processors. This is performed before shackling. The unconscious turkeys are then placed in shackles.
3. **Bleeding.** A cut is made across the throat so that both branches of the jugular vein are severed at or close to their junction.
4. **Scalding.** The feathers are loosened, usually by the sub-scald method in which the bird is immersed in agitated water at 140°F (60°C) for about 30 seconds.
5. **Feather removal (picking).** The feathers are removed by a rubber-fingered machine or plucker.
6. **Evisceration.** Usually, the turkey is suspended by the head and both hocks, a crosswise cut is made between the rear end of the keel and the vent, and the intestines are removed.
7. **Chilling.** The eviscerated carcass is chilled in ice water or ice slush to an internal temperature of 35–39°F.
8. **Packaging.** After chilling, the carcass is drained, a plastic wrap is applied, the air in it is exhausted by vacuum, and the wrapper is sealed. The bird is then readied for freezing or for marketing fresh, chilled, and unfrozen. Alternatively, further processing occurs.

Inspection

Turkeys are inspected at the processing plant by USDA/FSIS Inspectors in the US. This examination of birds is for indication of disease or other conditions that might make them unfit for human consumption. In order to pass inspection, birds must be healthy at slaughter. In the United States, all ready-to-cook poultry and poultry products are federally inspected. Antemortem inspection of poultry is required before it enters the processing plant. This is a spot check of each load of birds, not of each individual bird. Postmortem inspection of each bird can occur when the abdominal cavity is opened and the visceral organs are removed (see Chapter 12).

Grading

Grading consists of identifying individual birds according to quality. Final grading of ready-to-cook poultry is after the birds are eviscerated and cooled and before they are packaged, frozen, or further processed, but not while they are still warm. In the United States, turkeys are graded by the USDA's Agricultural Marketing Service (AMS). The AMS assigns the following grading shield:

- US Grade A. Poultry without defects and sold in stores as whole turkeys.
- US Grades B and C. Poultry with defects and not normally sold in stores as whole turkeys. Rather, they are further processed.

Turkeys of grades A, B, and C have passed inspection and are considered as safe to consume.

Further Processing of Turkey

There are distinct advantages of further processing. The products are lower in fat, saturated fat, and calories (see Table 20.12)

Further processing creates turkey ham and smoked turkey; deli sliced turkey, sliced turkey ham, and sliced smoked turkey; turkey bacon with alternating white and dark meats; mechanically deboned turkey meat; ground turkey meat products such as turkey hamburger, sausage, and chili; and ground turkey meat products in an emulsion (e.g., frankfurters, bologna) (see Figure 20.10). Following packaging, products can be pressure pasteurized. This reduces bacterial contamination and extends shelf life.

Examples of prepared turkey are illustrated in Figures 20.9 and 20.10. There has been marked growth in the production and sale of deli-style sliced roast turkey and turkey ham in the United States. Such deli meats are prepared using high-speed slicers in clean rooms. Deli-style sliced turkey is marketed at grocery stores, via traditional delis, and at some fast service restaurants. For instance, the menu at Arby's includes roast turkey sandwiches, wraps, and sliders,

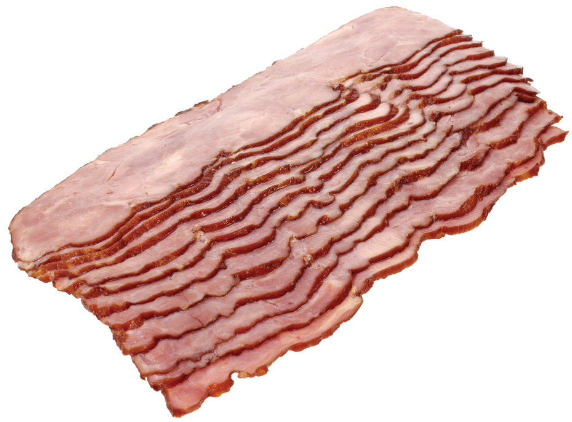


Figure 20.10 Sliced turkey bacon is an example of further processed turkey. (Source: BW Folsom/Shutterstock)

and thinly sliced roast turkey is an important part of many of Subway's deli sandwiches. Table 20.13 summarizes the prices of various further processing parts of turkeys in 2017. Prices will, of course, change with time. However, the relative values of different parts are anticipated to remain relatively stable.

Other Products and By-Products

Offal, bone, and feathers from turkeys are processed and marketed in a manner very similar to that of chickens (see Chapter 19 for details).

Table 20.12 Comparison of turkey products with more conventional pork products.

Product	Protein	Fat	Calories
Turkey bacon (uncooked)	15.9	16.9	226
Pork bacon	*12.6*	*39.7*	*417*
Turkey breakfast sausages	16.7	8.3	135
Conventional (pork) breakfast sausages	*16.9*	*23.7*	*288*
Turkey frankfurters	19.6	10.7	179
Pork frankfurter	*12.8*	*23.7*	*269*
Turkey ham	16.7	5.9	143
Ham (cured pork)	*18.5*	*18.5*	*246*
Thinly sliced turkey breast (cooked)	17.6	2.0	98
Sliced ham (cooked)	*16.6*	*8.6*	*163*

Table 20.13 Relative prices of further processing parts of turkeys in 2017.

Part of Turkey	Price in 2017 US$ per 100 kg (per 100 lb)
Breasts	
1.81–3.63 kg (4–8 lbs)	383 (174)
Tom	339 (154)
Trim	123 (56)
De-strapped tenders	268 (122)
Drumsticks	
Tom	125 (57)
Hen	119 (54)
Wings (full cut)	
Tom	84 (38)
Hen	81 (37)
Necks	84 (38)
Thigh meat	260 (118)
Mechanically separated	74.5 (33.87)

Calculated from data from the USDA's Agricultural Marketing Service.

Export of Turkeys

The United States is the largest exporter of turkey meat globally with about 0.3 million metric tons exported per year. The largest markets are Mexico, China (including Hong Kong), and Canada.

20.8 Turkey Breeders and Reproduction

The essence of turkey egg production is the large ovary. There is a hierarchy of follicles (see Figure 20.11). As the follicles mature, they grow in size during the accumulation of yolk. This is due to the yolk precursors in the blood passing into the ovum; the yolk precursors being produced by the liver. The largest follicle in the hierarchy of large yellow follicles is the next to be ovulated. The ovulated ovum passes down the oviduct gaining egg white, membranes, and the shell (see Figure 20.12).

Breeder hens (see Figure 20.13) are the equivalent of broiler breeders, with production of turkey poults instead of the broiler chicks. Goals for egg production are shown in Table 20.14.

Textbox 20E

A Deeper Dive: Meat Quality, Genetics, and Heat Stress in Turkeys

Meat quality is critically important to consumers and hence to the poultry industry. There are situations when poultry meat is not at the very high standard we expect. One such circumstance is pale, soft, and exudative **(PSE)** meat. PSE meat was first identified in pork. In pigs, PSE was demonstrated to be a genetic condition being found in animals susceptible to the anesthetic gas halothane. The underlying cause is a mutation in the ryanodine receptor gene—a protein (in calcium release channels) that is important to calcium levels in muscle. The presence of the mutation was associated with improved growth and, hence, selection for growth increased the number of animals with the mutation. The appearance of PSE is influenced by environmental factors such as heat.

Is There PSE in Poultry?

The simple answer is yes, PSE is a problem in poultry meat and resembles the problem in pigs. The incidence of PSE is increased by seasonal heat stress. Moreover, there is a more than threefold increase in the incidence of PSE in halothane-sensitive turkeys subjected to heat stress (McKee and Sams, 1997; Owens et al., 2000). It is estimated that PSE costs the turkey industry $200 million per year (Owens et al., 2009). An example of the problem with PSE on the eating experience is that the uptake of marinade is much lower (reduced by two-thirds) in PSE turkey meat (Sporer et al., 2012). As might be expected, PSE is associated with changes (reductions) in the level of mRNA for both the α and β ryanodine receptors together with the expression of other calcium-regulating genes (Sporer et al., 2012).

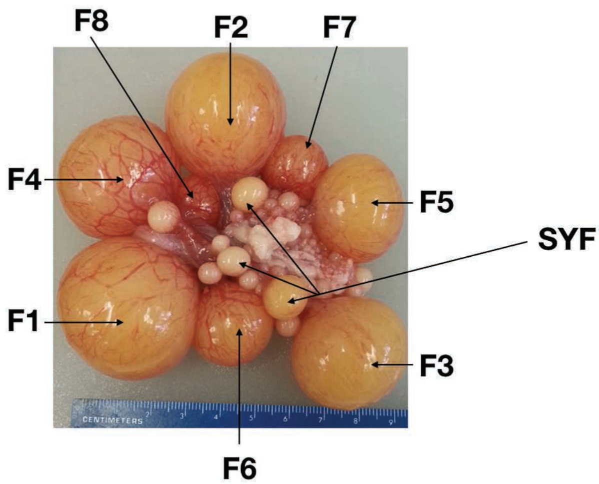


Figure 20.11 Turkey ovary showing hierarchy of large yellow follicles labeled F1–F8. The F1 will be ovulated first after about a day, the F2 the following day, the F3 the day after that. The large yellow follicles are filling with yolk. In addition, there are small yellow follicles (SYF) and small white follicles. (Image courtesy of Alan Johnson, Pennsylvania State University)

Figure 20.12 Turkey eggs. (Source: Photomaster/Shutterstock)

Table 20.14 Goals for egg production by Nicholas Select turkeys.

Week	Production (%)	Hatchability (%)
1	31	79
2	55	82
3	72	83
6	70	86
10	66	86
20	56	80
28	49	73

Based on Aviagen Turkeys.

Housing

The three types of housing systems used for breeder turkeys are (1) confinement breeding facilities, (2) range breeding facilities, and (3) a combination of confinement and range. The latter two are now uncommon in North America, but there is a move back to free-range systems in Europe, particularly in the UK. Formerly, range breeding was commonplace; the breeders were allowed to roam in open pens with range-type or open-shed shelters. The space requirements for turkey quarters, feeders, and waterers are important, and they are affected by age, size (large-type versus small-type), and kind of rearing (brooder house, confinement, semi-confinement, or range).

Nutrition of Breeding Turkeys

The nutritional requirements and practices for breeding turkeys are different from those for turkeys raised for meat. This is analogous to the situation with broiler breeders (see Chapter 19). There is also a seasonal effect on feed consumption. The nutritional requirements for reproductively active hens and toms are shown in Table 20.15. Feed intake is influenced by environmental temperature. For instance, for every 10°F (6°C) decrease in temperature expect a 6% increase in feed consumption.

- **Feeding Adult Breeder Turkey Hens**: The nutritional requirements show an abrupt change when they come into egg production. At that time, there are markedly increased requirements for protein and calcium to meet the needs of egg production (see Table 20.15).
- **Feeding Adult Breeder Turkey Toms**: The diet for male breeder turkeys is restricted to prevent obesity and to reduce feed costs.
- **Feeding Growing Turkey Hens**: The nutritional requirements vary gradually with age. Examples of stepwise changes in turkey-breeder growing-hen diets during growth are shown in Table 20.15.
- **Feeding Growing Breeder Turkey Toms**: The diet for growing male breeder turkeys is restricted to prevent obesity and to reduce feed costs.
- **Breeder Management**: Frequently, the failure of turkey breeding programs can be traced to problems of management.

Turkey Breeders and Reproduction

Reproduction in turkeys is highly seasonal with long day lengths required for reproduction. Under

Table 20.15 Nutritional requirements for breeder Nicholas turkeys.

Diet and Age in Weeks	Energy—kcal per kg	Protein % (Lysine %)	Calcium %
Starter Hens 0–2 Toms 0-4	2756	25–26 (1.55)	1.45
Rearer Hens 2–6 Toms 4–6	2756	21–22 (1.35)	1.35
Grower 1 6–10	2800	16–17 (0.90)	1.25
Grower 2 Hens 10–12 Toms 10–16	2800	12–14 (0.65)	1.10
Grower 3 Hens 12–29 Toms 16-selection	2800	9–11 (0.45)	1.00
Breeder: Hens			
Hot environment	2865	18–20 (0.88)	2.90
Moderate environment	2820	17–18 (0.83)	2.85
Cool environment	2800	15.5–16.5 (0.88)	2.80
Breeder: Toms			
Full fed	2800	9–12 (0.65)	1.0
Control	2866	14–15 (0.65)	1.10

Based on Aviagen Turkeys.

natural conditions, turkey hens start egg production in spring, when the natural light gets to about 14 hours per day after being as low as 8 hours per day in the winter months (see Figures 20.13 and 20.14 for adult turkeys).

For year-round turkey production it is essential to also have breeding throughout the year. In most of the Northern Hemisphere, turkeys hatched between August 1 and April 1 are considered out-of-season birds. Breeding throughout the year is achieved by lighting programs.

Definitions

Photostimulation: The induction of a physiological process (such as reproduction) by long day lengths. Turkeys are strongly photosensitive. Hens are lit at 29/30 weeks old with an increase in the day length to 14L:10D.

Photorefractoriness: When an animal or plant no longer responds to a stimulatory photoperiod. A period on short day lengths is required to break photorefractoriness. Turkeys between 17 weeks old to 29/30 weeks old are on a photoperiod of 6L:18D to prevent photorefractoriness.

Day Length or Daily Photoperiod: An example of a photoperiod is 6L:18D. This is equal to 6 hours of lights on (day) and 18 hours of lights off (night) in a lightproof barn.

Photophase: The time of light or lights on or subjective day.

Scotophase: The time of darkness or lights off or subjective night. The light intensity during the scotophase should be less than 0.4 lux or 0.04 foot candles.

Photoreception: The action of light on specific photosensitive proteins (e.g., opsins) in photosensitive cells, such as in the eye, and parts of the brain, such as the hypothalamus. Interaction of light with the photosensitive proteins leads to changes in the cell (signal transduction) and these lead to nerve impulses.

Hens are light restricted between 18 and 20 weeks of age (placed on a short day length). To bring turkey hens into lay at about 30 weeks of age, the hours of light are increased to 14L:10D. This is known as **photostimulation** or lighting of the turkeys. The increase in day length, or photoperiod, also initiates a process that leads to the birds being unresponsive to these long day lengths. This is photorefractoriness.

After an initial peak in eggs produced, egg production declines. After about 20 weeks of laying eggs, the rate of egg production falls to a low level. Moreover, turkey hens start to show incubation/nesting behavior. If they are permitted to sit on the eggs, laying stops completely. The breeder hens can be recycled or brought back into lay by restricting day length to 6–8 hours of light per day for about 6 weeks, then increasing the day length again. Reproduction can be divided into the following phases:

- **Break photorefractoriness**: Place immature hens on a short day length

Figure 20.13 Turkey hen and eggs. (Source: Photomaster/Shutterstock)

Figure 20.14 Sexually mature tom (male) turkey. (Source: Shutterstock, photo by veleknez/Shutterstock)

- **Photostimulation**: Increase day length to 14 to 15 hours/light per day.
- **Development** of the ovary and reproductive tract (oviduct).
- **Egg production peaks.**
- **Egg lay declines** due to photorefractoriness and/or shift to incubation physiology with nesting, and so on.
- **Transfer to short days** to recycle (or "break" photorefractoriness) and prevent nesting and incubation.
- **Increase day length** for reproductive resurgence.

Following insemination, spermatozoa are stored in sperm ducts (glands or nests) for about 10 days in the hen's vagina. After each egg is laid, some of the sperm leave the sperm duct and travel to the top of the oviduct to fertilize the next egg being laid. This is the only time an egg can be fertilized. As soon as the yolk is coated with egg white, the sperm cannot get to the ovum.

Egg Production and Hatchability

Egg production in turkeys peaks at week 3 at about 72% and declines gradually to about 50% at week 26. Each hen produces between 100–130 eggs per cycle. Hatchability also shows changes during egg production: 79.5% in week 1, 86.5% in weeks 6–10, and 75.5% in week 26.

Lighting for Breeder Turkeys, or Photostimulation

Commercial turkey hens are placed on short day length lighting (< 8 hours of light per day) at about 18 weeks of age to prevent reproductive development when they are too young or small for optimal production and to prevent photorefractoriness. Feed may be restricted to ensure that a target body weight is not exceeded. At about 29–30 weeks of age, the day length is increased to a long day length (14 hours of light per day) to bring about rapid sexual maturation (see Table 20.16). Toms should be lit 3 weeks prior to lighting hens to assure semen being ready at the time of mating (or semen collection for artificial insemination).

This is equivalent to the increases in day length of spring that bring about breeding in wild birds. Breeder hens should not be subjected to lighting earlier than 29 weeks of age. The recommended light intensity is 5 to 7 foot-candles (50–70 lux), 12 in. off the ground. A uniform light pattern is also important.

Table 20.16 Lighting program for turkey breeder hens.

Age (Weeks)	Day Length	Light Intensity (Minimum) Lux (FC)
0–17	Between 10L:14D to 14L:10D if no natural light. If natural light, bring to the above by supplementary light.	80–100 (8–10)
17–29/30 (when lighted)	To light proof barn with 6L:18D.	20–100 (2–10)
29/30 and onwards	14L:10D if no natural light. If natural light, bring to the above by supplementary light.	120 (12)

Based on Aviagen Turkeys.

How Is Photoperiodism Controlled?

Light indirectly via eye or directly on hypothalamus
↓
Increased release of gonadotropin-releasing hormone (GnRH)
↓
Anterior pituitary gland
↓
Increased release of luteinizing hormone (LH) and follicle stimulating hormone (FSH)
↓
Ovary
↓
Estrogens such as estradiol + progesterone and androgens (e.g., testosterone)

Development and maturation of the ovary is induced by LH and FSH. The ovary releases estradiol (together with other hormones such as progesterone and testosterone). Estradiol (and other ovarian hormones) causes the oviduct to grow, mature, and supply egg white and shell.

Artificial Insemination

Today's broad-breasted turkeys would not be practical without artificial insemination. Turkeys with a conformation that pleases the consumer and a meat yield that satisfies the processor do not have the agility to mate often and successfully. Males (toms) are much larger than females (hens). Mating is not only problematic but may physically injure the hen.

TEXTBOX 20F

A Deeper Dive: Heat Stress and Egg Production in Turkeys

High environmental temperatures greatly impair reproductive performance in turkeys (Rozenboim et al., 2004). What happens to female turkeys exposed to high environmental temperatures? Hens at 42°C exhibit the following: In one study, for example, female turkeys exposed to an environmental temperature of 107.6°F (42°C) exhibited an elevated body temperature (by over 1°C); deceased egg production (by 20% after 11 days), decreased egg weight (by 14%) and hence presumably poult weight and poult growth; dramatically decreased blood levels of two of the most important sex steroids, namely testosterone and progesterone; depressed blood levels of the other important sex steroid, namely estradiol; and ovarian regression (Rozenboim et al., 2007).

The turkey industry in the United States and Canada has used artificial insemination for breeding for over 60 years. Turkey semen cannot be frozen and then both reliably and effectively used for insemination. Because of this, the storage time for turkey semen is limited. The semen may be diluted with an extender (containing isotonic salts and proteins, including yolk) to increase the number of hens that can be inseminated and to extend the life of the semen. The reason for almost complete utilization of artificial insemination for breeding turkeys is animal safety. Insemination can occur every 7 to 10 days because spermatozoa are stored in the oviduct in sperm ducts. Toms should be "pre-milked" (ejaculated) at least once before collecting semen for artificial insemination. If they are not pre-milked, they may not give enough semen for the first artificial insemination.

The advantages of artificial insemination include increased fertility, reduced damage to female during mating, reduced use of large males that have difficulty mating, allows for the separation of males and females, semen can be evaluated for quality (e.g., spermatozoa motility and number of abnormal spermatozoa), and semen can be diluted or extended so fewer males need to be kept.

Can Turkey Semen be Sexed?

The simple answer is no! In cattle, X (female offspring) and Y (male offspring) spermatozoa can be separated. Semen can then be sold with a "guarantee" of a bull or heifer calf. Sexing semen in turkeys is not possible because the male is homozygous (ZZ) and the female gamete (ZZ or ZW) determines the gender of the poult.

Collection of Semen

This requires two people. The operator holds the tom's legs and operates the semen collection equipment. The milker massages the area around the cloaca, places pressure below the phallus and then strokes the phallus to induce ejaculation.

Turkey Semen

Turkey semen has a volume of ~0.35–0.5 ml and a concentration of spermatozoa of 6 to > 8 billion per ml. Good semen is thick and has a pearly white appearance. After dilution and holding at 4°C, 150–300 million spermatozoa are inseminated into each hen; thus 20 hens can be inseminated from a single ejaculation. Hens are inseminated every 7–10 days

Semen with low spermatozoa counts can be grayish and watery. Toms producing semen with low concentrations of spermatozoa are culled, as are toms producing a low volume of semen. Yellowish semen should not be used. Males that continue to produce yellow semen are not used and are culled.

Insemination of Hens

Insemination is performed on hens that appear to be receptive. Hold the hen and apply pressure to around the vent to evert the cloaca such that the oviduct is protruding. Insert a straw containing the diluted semen and deliver the semen into the vagina.

Natural Mating

In the natural process of fertilization, mating takes place when the hen is receptive. Hens have a stronger propensity to mate a few days just before egg production starts and a few days thereafter. By the end of the season, they may mate less frequently. In mating, the hen everts the vagina beyond the lips of the cloaca and the tom's phallus deposits semen directly on the everted tip of the vagina. The hen immediately withdraws, carrying the semen far up the vagina. Sperm swim into tiny structures in the walls of the vagina, called sperm ducts or nests. A few leave and are carried by the action in the hen's oviduct and their own action (swimming) to where fertilization takes place.

Other Issues in Turkey Reproduction

Nests

Hens lay in nests. The tip-ups or gates close behind the hen when she enters and remains closed until she leaves. As she leaves, the tip-up should automatically reset so another hen may enter. Nests can be arranged in rows and should be operational well in advance of lighting the hens. Individual nests should be at least 2 ft (0.6 m) high, 1 1/2 ft (0.45 m) wide, and 2 ft (0.6 m) long. Nests should be placed on the floor or about 6 in. (15 cm) off the floor. Materials for nesting litter include sawdust and wood shavings.

Broodiness

Broodiness is a natural behavior in birds with them incubating, hatching eggs and, in many cases, caring for the chicks. In turkey hens, like other birds, broodiness is seen and is due to the hormone prolactin. In turkeys, broodiness is a problem, as it is associated with the cessation of egg production and hence less eggs. Broodiness should be halted as soon as it is detected. Factors increasing the incidence of broodiness include the presence of eggs in a nest, hens laying eggs on the floor, eggs laid at night, and hot weather.

Approaches discouraging the development of broodiness include collecting eggs from nests very frequently, discouraging eggs being laid on the floor, assuring sufficient numbers of nests, sufficient ventilation, and—where necessary—cooling by foggers, etc., and flushing water lines with cool water.

Approaches to reverse broodiness include separating birds from nests (and eggs) and placing them into novel environments, such as placing them on the floor for each of three days, and increasing day length by 4 hours for one day or to continuous lighting for one day.

Induced Molting

It is possible to get a second round of egg production from hens by inducing a molt. This is known as induced molting or induced rest. It also called forced molt. Reducing the day length to less than 10 hours of light per day brings about molting. To accomplish a reduction in day length, blinds are used in houses with natural lighting. Alternatively, the day length can be decreased in lightproof confinement houses. Reduced day length causes any remaining egg production to cease and a molt to start. Shifts in diet augment the effects of the day length change. After molting is complete, the hens are brought back into lay by increasing the day length.

20.9 Handling Eggs, Incubation, and Poult Production

Turkey Egg Summary

- Hatching time: 27.5–28 days (660–672 hours).
- Preheat eggs for 10–12 hours at 71.6°F (22°C).
- Incubate at 99.5–100°F (37.5–37.8°C).
- Ventilate to ensure carbon dioxide ($CO2$) levels stay below 0.5%.
- There are fewer than 50 hatcheries for turkey eggs in the United States.

Egg Handling

Proper egg handling is critically important. A fertile turkey egg contains the living embryo. This is delicate and can easily die. A newly laid egg has a temperature of 106°F (41°C). Inside, the embryo is growing very rapidly. There is no air cell, the shell is damp, and the embryo is very susceptible to sudden temperature changes. As the egg cools, embryo growth slows and by the time the internal temperature gets down to 80°F (27°C), growth is arrested. Cooling eggs too fast reduces fertility and hatchability.

Eggs should be collected frequently, especially during cold weather. Dirty eggs usually show lowered hatchability and may transmit disease. Also, they are the main reason for exploders in the hatchery. Washing turkey eggs intended for hatching appears to be a debatable practice. Not only is washing ineffective in sanitizing the eggs, it may actually be harmful to fertility.

Egg fumigation can be performed with formaldehyde to kill bacteria on the shell and prevent disease outbreaks in the poults. However, fumigation can influence the embryo and reduce hatchability.

Egg Storage

Eggs should be allowed to cool slowly, and then be stored at 55–65°F (13–18°C) with 70% relative humidity. A recommended procedure is to pack eggs in pre-cooled cases, small end down. Turkey eggs can be stored for between 3 and 10 days. Since both fertility and hatchability decline as the holding period increases, holding turkey eggs longer than 2 weeks is not recommended.

Incubation

Turkey eggs are incubated at about 99.5–100°F (37.5–37.8°C) and a relative humidity of 55–60% (see Table 20.17 for recommended incubator temperatures). Also, proper ventilation is essential. The developing embryos require air containing 20% oxygen and not more than 0.5% carbon dioxide. Since the oxygen requirements of the embryos increase as they develop, rates of ventilation must be increased as the hatch progresses. The eggs should be turned at least five times daily, and preferably every 2 hours during incubation. With machines equipped with turning devices, this is easily accomplished. The incubation period for large-type turkey eggs is 28 days. Eggs from small-type turkeys tend to hatch in 27 to 27 1/2 days. Only clean eggs with sound shells should be placed in the incubator. Washing is not recommended for turkey eggs.

Table 20.17 Range for incubation temperatures for turkey eggs.

Time	Incubator Temperature °F (°C)	Shell temperature °F (°C)
Week 1 of incubation	99.5–100.6 (37.5–38.1)	99.7–100.6 (37.6–38.1)
Week 2 of incubation	99.5–99.9 (37.5–37.7)	99.5–100.6 (37.5–38.1)
Week 3 of incubation	98.6–100.6 (37.0–38.1)	99.5–100.6 (37.5–38.1)
Week 4 of incubation	98.6–100.6 (37.0–38.1)	99.5–100.6 (37.5–38.1)

Data from Aviagen Turkeys.

If incubation temperatures are even slightly out, there can be marked problems. If incubation temperatures are too high, there is increased embryonic death, gross deformities, and reduced poult quality. If incubation temperatures are too low, hatching rates are reduced or hatching is delayed.

Issues

Determine the temperature of the air in the incubator and on the egg shells, ensuring they are within the goal range. Check the calibration of the incubator and thermostats. Determine whether ventilation is sufficient to bring shell temperatures to the goal range. Determine whether ventilation is bringing humidity to below desired levels. Determine whether humidifiers are bringing humidity to the desired levels.

At the Hatchery following Incubation

Following hatching, poults are removed from the incubator. They are sexed (so males and females can be reared separately), the beak and toes are conditioned (trimmed), and they are vaccinated. Poults are then taken to the grow-out houses for brooding and growth (see Section 20.6).

20.10 Niche Markets

Producers receive a premium for specific varieties of turkeys or birds raised under specific conditions, such as being raised spending at least part of their time outside. Niche markets for turkeys include the following (it should be noted that more than one category may being employed):

- Organic, which requires turkeys to spend at least part of their time outside, to receive organic feed, and to only receive organic-approved disease control measures.
- Range or free-range turkeys.
- Pasture turkeys (that is, range turkeys with access to pasture and moved to fresh pasture on a regular basis).
- Heritage varieties.
- Locally sourced.
- Produced on a family farm (or small family farm).

A general issue is animal health. It is not possible to isolate turkeys outside from wild birds, rodents, insects, etc. These can be reservoirs and/or vectors for pathogens. Hence, there are significant risks from infectious diseases together with both ectoparasites and endoparasites (see above). Another issue is predator control.

Predator Control

A tight fence around the range area will reduce predator entry. A perimeter electric fence 10 to 18 in. (25 to 45 cm) above ground level and 2 to 3 ft (0.6 to 1.0 m) outside the poultry fencing will further reduce predatory entry. When an electric fence is used, it should be properly constructed; otherwise, it may be hazardous. Some growers ward off predators with devices that produce loud noises or by keeping a dog leashed near the range area.

Heritage Varieties

Heritage Breeds of turkeys include Beltsville Small White or Midget White, Black or Black Spanish (see Appendix I Figure 4A), Bronze or Standard

Bronze, Bourbon Red, Narragansett, Royal Palm, Slate or Blue Slate, and White Holland.

There are also breeders and hatcheries supplying traditional or heritage varieties. Examples include Aviagen Turkeys with the brand Valley of the Moon with traditional Nicholas bronze, auburn, black, and white turkeys; Hybrid Turkeys with alternative/heritage products Orlopp Bronze, Artisan Gold, and MiniCLASSIC; and Murray McMurray Hatchery with multiple turkey varieties.

Specific Recommendations for Range and Pasture Turkeys

Moving Turkeys

When poults are about 8 weeks of age, they are ready to be moved to the range. Movement to the range is most critical and should be carefully planned. Two things should be checked before moving poults to the range: (1) the 5-day or 1-week weather forecast, and (2) the readiness of equipment. Avoid moving poults when the weather is threatening. Cool, wet, and rainy weather places a severe stress on poults that have just been moved to range. It is best to move in the early morning because this allows poults plenty of time to locate water, feed, and shelter before nightfall. Never move in the heat of the day, for this is hard on both birds and handlers. Some growers move about one-third of their poults the first morning, then skip a day or two and move the remainder of the flock. Large wire-enclosed four-wheel trailers are best for moving turkeys to ranges. Moving trailers may be constructed so that the birds can be loaded and unloaded by driving or herding. Range turkeys can be driven or herded from place to place. One person can control a good-sized flock. Dogs can be used for driving turkeys if they are well trained and gentle.

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Poultry Industry, Business, and Marketing

21

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Define "vertical integration."
2. List facilities and services provided by the producer in marketing and production contracts.
3. List facilities and services provided by the bird owner in marketing and production contracts.
4. List the advantages and disadvantages of vertical coordination.
5. List the three major types of business organizations.
6. Know the roles of the grower and integrator in the broiler industry.
7. Know the difference between assets and equity.
8. Know what collateral is used by growers to borrow money for the construction or renovation of new poultry houses or equipment.
9. List the advantages and disadvantages of production contracts to growers and integrators.
10. Understand global trade in poultry meat, offal, eggs, and egg products, including the major players.
11. List job opportunities in the poultry industry.
12. List the top exporters and importers of poultry products.

21.1 INTRODUCTION

Production of poultry and eggs has increased globally due to (1) the continuous improvement of genetics, (2) excellent nutrition, (3) superior animal health programs, (4) biosecurity and animal welfare, and (5) very effective business models. Items 1–4 have relied on research and educational programs in universities. Moreover, critical research is occurring, and has occurred, in both company and government laboratories. While items 1–4 were necessary to the success of poultry production, they were not sufficient. The development of very effective business models was critical and depended on leaders in the industry, such as John W. Tyson (father) and Don Tyson (son) of Tyson Foods (Springdale, Arkansas) and Arthur Perdue (grandfather), Frank Perdue (son), and Jim Perdue (grandson) of Perdue Farms (Salisbury, Maryland).

21.2 VERTICAL COORDINATION

What is vertical integration and vertical coordination? Much of the poultry and pork meat production involves the contracting of certain services by the farmer (for the broiler industry, these are called growers) with highly integrated poultry and pork processing companies in a vertically coordinated system. In contrast, vertical integration encompasses ownership on all of the steps in productions. Vertical coordination occurs between the stages of the poultry industry (see Figure 21.1 for broiler chicken production and Figure 21.2 for egg production). The levels of control from the contractors or integrator vary, from the least to the most, in the following manner: open production (open or spot market), market contracting (or market-specific contract), production contracting (or resource providing the contract), and ownership (vertical integration).

Open Production

Open production is also known as an open or spot market. In this, there is very limited coordination. What limited coordination that exists is provided by cash or spot prices.

Market Contracting

Market contracting involves the grower contracting with the processor for number, time, and quality characteristics, together with pricing method. (The processor has a limited involvement in some of the decision making of the grower.)

Production Contracting

Production contracting involves the processor (contractor or integrator) having a major role in producer/grower decision making. The processor has ownership of various production inputs (e.g., feed) and acts as the market for farm products (poultry or eggs).

21.3. Vertical Integration

Vertical integration is a process in which a single company owns two or more stages in the supply or value chain (e.g., production and processing) with common management control.

Vertical Coordination in the Broiler Industry

Vertical coordination has long dominated the broiler chicken industry (see Figure 21.1). Coordina-

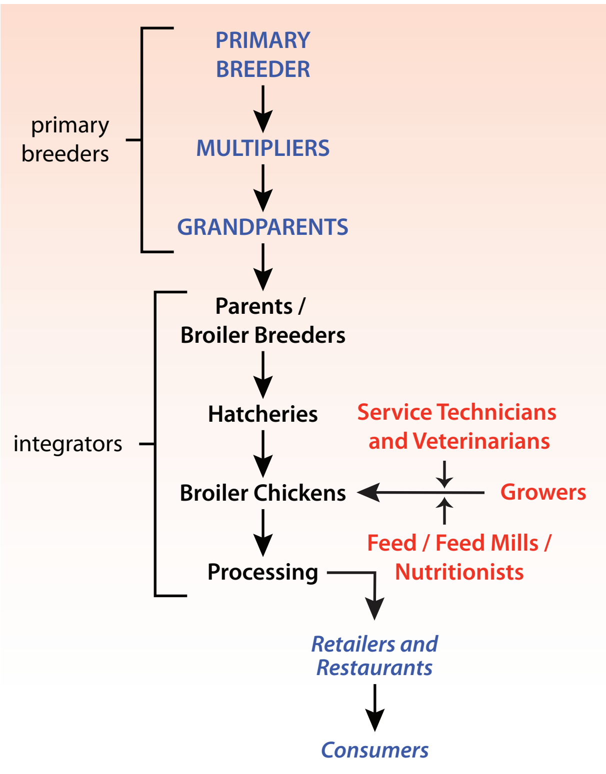

Figure 21.1 Schematic of broiler chicken production, showing primary breeders and the various roles of integrators. An integrator may own the primary breeder.

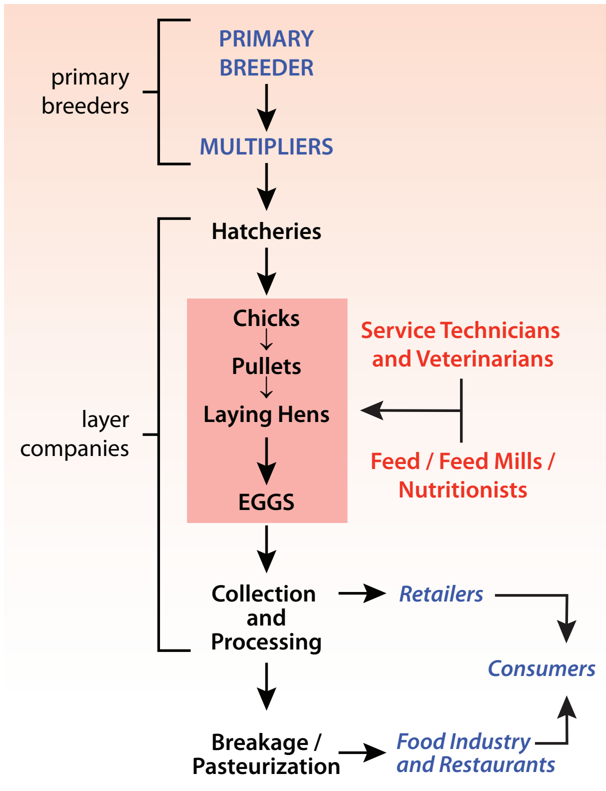

Figure 21.2 Schematic of egg production, showing primary breeders and the roles of the layer company.

tion was initially led by the feed industry but is now led by processors or integrators (e.g., Tyson Foods, Perdue Farms, etc.). There is a mixture of production contracts (~ 80%) and complete vertical integration (> 18%). Tyson Foods is the leading producer of broiler chickens and further processing in the United States (see Figure 21.3). Sales of Tyson poultry, pork, and beef (including Hillshire Brands) are about half to consumers in grocery stores and about 30% to food services such as restaurants.

Contracts specify the use of company-supplied chicks from company-owned hatcheries. These come from grandparent stock from primary breeders. For instance, chicks for Tyson come from the company's primary breeder, Cobb-Vantress.

Primary Breeders

There are three primary breeders for broiler chickens globally:

- **Aviagen**. Brands include Arbor Acres, Hubbard, Indian River, Rowan Range, and Ross.
- **Cobb-Vantress**. A wholly owned subsidiary of Tyson Foods.

This vertical coordination represents a high degree of integration with integrators (poultry producing or processing companies) owning the hatcheries, birds, feed mills, feed, processing plants, and trucks. Growers own the poultry houses and care for the growing chickens. The coordination or integration is achieved by production contracts between the integrators and the growers. Growers specialize in specific weight ranges of broiler chickens as specified in the production contracts.

Production Contracts

Production contracts involve the processor (or integrator) providing baby chicks (but retaining ownership), field and veterinary services, feed, and oversight by integrator. Production contracts also involve the grower providing care for the chickens and specifically labor, utilities (water for the birds and cleaning, electricity for lighting and ventilation, and natural or propane gas for heating), new litter, disposal of spent litter and mortalities, poultry grower house(s), equipment, and the land around it.

Figure 21.3 Examples of further processed chickens from Tyson: (A) popcorn chicken and (B) chicken patties. Tyson branded chicken products are high quality and popular in many countries. Tyson is the largest producer of chicken meat and all meat in the USA. It is also the second largest producer of meat chickens globally. Tyson owns Cobb-Vantress, one of the major primary breeders for meat chickens. (Source: Keith Homan/Shutterstock)

The processor's catchers collect the broiler chickens at the desired weight and quality characteristics and transport them to the company's poultry processing plant where they are stunned, killed, plucked (defeathered), eviscerated, cleaned, and cooled. The grower receives payment based on per pound (or kilogram) live broilers produced and premiums/deductions based on performance. Growers are predominantly considered as small farmers with gross incomes of less than $350,000 per year (see Tables 21.1 and 21.2 for economic and social analyses, respectively, of growers in the United States). They have little other agricultural income. Typical growers are white males in their 50s whose formal education ended after completing high school.

Table 21.1 Growers' structure.

Parameter	Percentage
Gross cash income from broiler production[1]	71
Family farms	99
Incorporated	6
LLCs (not incorporated)	4
Size	
1–4 houses	47
5–8 houses	38
> 8 houses	15
Age of houses	
0–7 years	17
8–17 years	34
18–27 years	35
> 27 years	12

[1] Off-farm employment can give both additional income, health insurance, and other benefits.

In the tournament system, contracts include payments based on the relative performance of growers. There are some cooperatives that employ marketing contracts for organic and free-range broiler meat.

Tournament Systems for Raising Broilers

The integrator pays the grower per lb of live weight plus (or minus) a variable amount depending on performance above or below the medium. Performance is based predominantly on the feed to gain ratio. There may be a fixed top and fixed bottom payment. The integrator has the information on the feed used and the live weight as the catchers are employed by the integrator.

Table 21.2 Social structure of broiler growers.

Sex/Ethnicity	Percentage
Primary operator male	92
Primary operator female	8
White non-Hispanic	96
African American	1
Asian	1
Hispanic	1
Native American	1

Issues with Tournament Systems of Payments

The following is a list of issues brought up about tournament systems:

1. If the growers in the same tournament are located in the same geographical area, the birds in the poultry house will be exposed to similar weather and other environmental conditions.
2. Some argue that growers cannot anticipate revenue as they do not know what will be the middle. Moreover, there may be a market price clause. This has led to some grower dissatisfaction.
3. Contracts can be discontinued if grower performance is below a certain level.
4. Sales of poultry houses and land do not automatically transfer the contract with the integrator to the new owner. This would limit ability to obtain loans without the contract. To resolve this, integrators can issue letters of intent but this may be conditional on the houses being renovated to meet expectations.

Labor and Economies of Scale

Large grower operations should realize economies of scale. As might be expected, the hours of labor required rises with the number of grow-out houses. It can be clearly seen from Table 21.3 that the total number of hours needed does not go up proportionately. For instance, while the number of grower houses goes up five-fold from 1–2 to 7–8 houses, hours needed to be worked only doubles.

Depreciation

In the United States, poultry houses can be depreciated for tax purposes by either the **General Depreciation System** (depreciated over 10 years) or the **Alternative Depreciation System** (also depreciated

TEXTBOX 21A

Economics of Broiler Production for the Grower

Assumptions

1. Fixed payment to middle producer per pound: 5¢ ($0.05) [equivalent to 11¢ ($0.11) per kg].
2. Market at 6.18 lbs (US average for 2017).
3. Cost per house: $200,000.
4. Houses: 4.
5. 20-year loan and interest at 6%: $68,772 per year (also assumes 20-year contract).
6. Land: 10 acres purchased at $2000 per acre.
7. 20-year loan and interest at 6%: $1,716 per year.
8. Birds placed per house: 25,000.
9. Flocks per year: 6 (antibiotic-free flocks per year 5).
10. Labor costs: $500 per week or $26,000 per year (if performed by grower zero cost but grower should be paying him/herself).

Modeled Results

1. Birds placed: 100,000.
2. Livability: 95%.
3. Number of chickens produced: 95,000 (6.18 lb birds).
4. Live weight (good pounds) of birds produced: 587,100 lbs.
5. Cycles per year: 6 (5 if antibiotic-free).
6. Live weight (good pounds) of birds produced per year: 3,522,600 lbs (antibiotic-free: 2,935,500 lbs).
7. Gross bird revenue per year: $176,130 (antibiotic-free: $146,775).

Costs to Grower

1. Utilities + propane/natural gas + water + litter (35% of gross revenue of birds): $61,645 (antibiotic free $51,371).
2. Labor: $26,000.
3. Repayment on building and land cost: $83,040.
4. Other costs not quantified—taxes, depreciation of buildings and equipment, repairs to buildings and equipment.
5. Total costs to grower: $170,685.5 (antibiotic free $160,411.3).
6. Gross bird revenue per year: $176,130 (antibiotic-free: $146,775).
7. Total costs: $170,685.5 (antibiotic-free: $160,411.3).
8. Net revenue to grower: $5,445 (antibiotic-free: $13,636).
9. Or if grower performs labor, net revenue to grower: $31,445 (antibiotic-free: $12,364).

Other Costs and Variable Income

- Sale or offset fertilizer costs using spent litter: $6000.
- Premium varying between -0.5 to +0.5 ¢ per lb depending on prime cost (reflecting feed conversion efficiency and livability). This would be a maximum of $17,613 (range down to minus $17,613).

TEXTBOX 21B

A Deeper Dive: Tournament Payment Systems

Agricultural Economists' Analyses

Tournaments can be either cardinal—competing for a fixed share of the "pie"—or ordinal—with "prizes" for top performance (Zheng and Vukina, 2007). Grower contracts are cardinal tournaments. Agricultural economists have looked at the system of broiler production with integrators and growers. Among their conclusions are that (1) it is an efficient system and that is why it has expanded so successfully and (2) there are no efficiency losses by mixing of players (i.e., growers) of uneven (heterogenous) abilities (Zheng and Vukina, 2007; Levy and Vukina, 2004).

However, problems have been identified. Vukina and Leegomonchai (2006) argue that integrators offer contracts to prospective growers on a "take it or leave it" basis. Also, integrators are more efficient exerting political influence and hence influencing federal and state regulations (e.g., Vukina and Leegomonchai, 2006; Zheng. and Vukina, 2007). There are asymmetric information problems with growers having less information for decision making compared to integrators

$$\text{Data} \rightarrow \text{Information} \rightarrow \text{Decision making} \rightarrow \text{Productivity} \uparrow \rightarrow \text{Profits} \uparrow\uparrow$$

Other possible systems include flat price—cents per lb, cents per bird, or cents per week; flat rate plus a feed: gain bonus; profit-sharing; and equity shares in the integrators.

Table 21.3 Labor requirement in hours per week.

Number of Houses	Grower and Family[1]	Hired Labor	Total
1–2	37	4	41
3–4	42	9	51
5–6	49	20	69
7–8	50	28	78
9–10	51	48	99
> 10	48	64	112

[1] USDA ERS refer to this as all operators.

over 10 years). In the General Depreciation System, depreciation can follow the straight-line method: 5% of the cost can be depreciated in year 1, 10% can be depreciated in years 2–10, and 5% can be depreciated in year 11. Alternatively, depreciation can follow the 150% declining balance method: 7.5% in year 1, 13.88% in year 2, 11.79% in year 3, 10.02% in year 4, 8.74% in years 5–10, and 4.37% in year 11. In the Alternative Depreciation System, depreciation follows the straight-line method: 3.33% in year 1, 6.67% in years 2–10, and 3.33% in year 11.

Information Sharing between Growers and Processors

The processors have data on which to make business decisions. Information provided to growers by the integrator includes the live weight per flock, feed intake, feed to gain ratio, and rankings (anonymous) to compare to a list of other growers in the tournament system.

Consolidation of Processors

Not only is the broiler industry highly vertically integrated but also there is increasing consolidation due at least in part to companies acquiring smaller companies (see Table 21.4).

Vertical Coordination in the Turkey Industry

Turkey production today is vertically coordinated (see Figure 21.1) with about 55% production contracts, more than 30% vertical integration, and around 10% sold on the spot market. Like the broiler industry, turkey production involves either production contracts (similar to those in the broiler industry) between grow-

Table 21.4 Increasing consolidation of broiler integrators/processors in the United States.

	Market Share Percentage of Broilers Processed in the USA			
	1980	1990	2000	2015
Top 3 Companies	21	35	40	46
Top 10 Companies	50	63	70	79
Top 20 Companies	71	79	87	96

TEXTBOX 21C

Importance of Feed Costs to the Integrator

Assumptions

- Cost of feed ingredients: $350 per ton or $0.175 per lb (appropriate steady state costs).
- Broiler chickens grown to 6.18 lbs with feed efficiency of 1.82 consumes 11.25 lbs feed.
- Chick costs: $0.35 each.
- Livability: 95%.

Costs

Assuming 1 million chickens marketed per week:

- Feed consumed (costs): 11,247,600 lbs or 5,624 tons ($1,968,330).
- Payment to growers: $1,854,000 (calculated from Textbox 21A).
- A planned 1 million chickens requires 1,052,632 chicks (accounting for mortality): $368,421.

Annual costs with 1 million chickens marketed per week:

- Feed consumed (costs): 584,875,200 lbs or 292,438 tons ($102,353,300).
- Payment to growers: $96,408,000.

Other costs:

- Annual costs of chicks: $19,157,895.
- Overhead (service technicians, veterinarians, etc.).

Excluding overhead, feed makes up 47% of costs.

Impact of Improvement to Feed Efficiency

Assuming 1 million chickens marketed per week, a two-point improvement in feed efficiency would save 3,214 tons of feed and $1,124,900 per year. Obviously, a larger improvement would result in greater savings.

ers and processors or vertical integration. Marketing contracts via cooperatives continue but their relative importance has declined. It is possible that niche products (free-range, organic, etc.) will be merchandized via cooperatives. Jennie-O Turkey Store is the leading processor of turkeys in the world.

21.4 World Trade in Poultry and Eggs

Table 21.5 summarizes global trade in poultry meat, offal, and eggs. The biggest category by either weight or value is chicken meat. World trade of poultry and eggs is increasing at a rapid rate. According to the UN's Food and Agriculture Organization (FAO), world chicken meat imports increased from 5.9 million metric tons (valued at $6.04 billion) in 2000 to 13.1 million metric tons (valued at $19.4 billion) in 2016. Similarly, world egg imports grew from 0.91 million metric tons (valued at $1.0 billion) in 2000 to 1.99 million metric tons (valued at $3.1 billion) in 2016 (see Table 21.5).

Table 21.5 Global trade (imports/exports) of poultry meats and poultry related products in 2013.

Type	Weight Traded in Metric Tons	Value of Exports/ Imports in US $
Meat		
Chicken meat	11.3 million	22.4 billion
Canned chicken	1.92 million	8.2 billion
Turkey meat	0.91 million	2.6 billion
Duck meat	0.19 million	755 million
Goose and guinea fowl meat	50 thousand	204 million
Offal		
Chicken liver	0.34 million	300 million
Duck liver	10.1 thousand	117 million
Goose liver	3.2 thousand	48.1 million
Fat liver (foie gras)	4.0 thousand	63.4 million
Eggs		
Eggs in shell	1.93 million	3.7 billion
Liquid eggs	0.32 million	701 million
Dried egg	67.7 thousand	368 million
Other eggs (predominantly duck & goose)	0.13 million	418 million

Data from FAOStat.

Items for Student Discussion and Research

1. Why do the values and weight of poultry meats, offal, eggs (shell, liquid, dried), etc., not line up consistently? Consider the differences in foods in different cultures and countries.
2. Why are some countries and regions exporters and others importers of poultry meats, eggs, and poultry-related products?

Imports and Exports of Poultry Meat

The largest net importers of chicken meat are Asia, Europe, and Africa (see Table 21.6). The largest exporters of chicken meat are South America, North America, and Europe (see Table 21.6).

Chicken meat exports from South and North America reflect an export-based business model. In contrast, importing and exporting in Europe reflects at least in part the European Union functioning as a single market. For example, Germany is both a significant importer and exporter of poultry meat (see Table 21.7). Saudi Arabia was the largest importer of chicken meat in 2016 (see Table 21.7). This is readily understandable as the country is oil rich but has a limited capacity for crop production and hence poultry feed. A similar argument can be made for the United Arab Emirates (UAE). The major exporters of chicken meat are the United States and Brazil. It seems strange that Hong Kong SAR is a major importer and major exporter. The former is explicable by Hong Kong SAR having little agriculture but also having processing and further processing (see Table 21.7).

Table 21.6 International trade of chicken meat in 2016.

	Quantity in Million Metric Tons		
Territory	Imports	Exports	Net
World	12.3	13.1	N/A
Africa	1.52	0.075	-1.45
Asia	5.83	1.39	-4.44
Europe	2.95	4.11	+1.16
South America	0.31	4.24	+3.93
North America	0.22	3.21	+2.99

Data from FAOStat.

Table 21.7 International trade of chicken meat in 2016.

Importers			Exporters		
Rank	**Country**	**Million Metric Tons**	**Rank**	**Country**	**Million Metric Tons**
1	Saudi Arabia	0.88	1	Brazil	3.96
2	Mexico	0.78	2	USA	3.11
3	China Hong Kong SAR	0.73	3	Netherlands	1.04
4	China Mainland	0.57	4	Poland	0.62
5	Japan	0.55	5	China Hong Kong SAR	0.52
6	United Arab Emirates (UAE)	0.50	6	Belgium	0.45
7	South Africa	0.48	7	France	0.31
8	Germany	0.45	8	Argentina	0.18
9	United Kingdom (UK)	0.38	9	Turkey	0.31
10	France	0.36	10	Germany	0.31

Data from FAOStat.

Consumption of canned chicken is low in the US. However, based on the level of imports, consumption of canned chicken is high in Europe and Asia (see Table 21.8).

Table 21.9 summarizes the top 10 countries for importers and exporters of canned chicken. Japan is the top importer of canned chicken followed by the United Kingdom, Germany, and the Netherlands. Of the top 10 exporters and importers of canned chicken, number seven and six, respectively, are from Europe. Two of the top three exporters of canned chicken, Thailand and Brazil, are both important poultry exporters.

Somewhat unexpectedly, there is considerable international trade in live poultry (see Table 21.10). Much of this reflects localized cross-border movement to processing plants from the USA into Canada or across borders in the European Union (see Table 21.11).

Table 21.8 International trade of canned chicken in 2016.

	Quantity in Million Metric Tons		
Territory	**Imports**	**Exports**	**Net**
World	2.05	2.16	N/A
Africa	0.02	0.00	-0.02
Asia	0.67	0.81	+0.14
Europe	1.15	0.83	-0.32
South America	0.04	0.23	+0.19
North America	0.08	0.25	+0.17

Data from FAOStat.

Table 21.9 International trade of canned chicken in 2016.

Importers			Exporters		
Rank	**Country**	**Thousand Metric Tons**	**Rank**	**Country**	**Number (Million)**
1	Japan	430	1	Thailand	508
2	United Kingdom (UK)	354	2	China Mainland	231
3	Germany	176	3	Brazil	213
4	Netherlands	168	4	Germany	179
5	Hong Kong SAR	93	5	Netherlands	120
6	France	66	6	Poland	88
7	Denmark	66	7	France	68
8	Belgium	47	8	Belgium	55
9	USA	44	9	Denmark	53
10	Ireland	39	10	Ireland	44

Data from FAOStat.

Egg Exports and Imports

The top two continents both importing and exporting chicken shell eggs are Europe and Asia (see Table 21.12).

Table 21.13 shows the top countries importing and exporting shelled eggs. There is high importing of shelled eggs to countries with little area for agriculture (Hong Kong SAR and Singapore) or where agriculture is difficult (Iraq and UAE). Germany is the top importer of eggs in the world. This latter situation reflects costs of production (e.g., labor) versus other European countries together with historical, cultural, and political considerations.

Some countries—such as the Netherlands, Turkey, Poland, and the US—have developed strong egg exporting capacity. There is significant trade of eggs

Table 21.10 Global trade (imports/exports) of poultry as live animals in 2016.

Poultry Type	Number	Value of Exports/ Imports in US $
Chickens	1.60 billion	2.35 billion
Turkeys	83.5 million	378 million
Ducks	38.3 million	72.4 million

Data from FAOStat.

Table 21.12 Trade of eggs (chicken) in 2016.

	Quantity in Million Metric Tons		
Territory	Imports	Exports	Net
World	2.11	1.99	Not applicable
Africa	0.06	0.02	-0.04
Asia	0.77	0.58	-0.19
Europe	1.12	1.21	+0.13
South America	0.01	0.02	+0.01
North America	0.06	0.15	+0.11

Data from FAOStat.

Table 21.11 International trade in live chickens in 2016.

Rank	Country	Number (Million)
Importers		
1	Netherlands	350
2	Germany	190
3	Belgium	145
4	Romania	94.0
5	Poland	73.0
6	Ukraine	69.0
7	Spain	67.0
8	Slovakia	61.4
9	Canada	57.1
10	Singapore	47.4
Exporters		
Rank	**Country**	**Number (Million)**
1	Netherlands	336
2	Germany	334
3	Belgium	134
4	Czechia (Czech Republic)	98.1
5	France	84.1
6	Hungary	80.1
7	Poland	77.9
8	USA	69.0
9	Denmark	66.7
10	Canada	57.1

Data from FAOStat.

Table 21.13 International trade of shelled eggs (chicken) in 2016.

Rank	Country	Thousand Metric Tons
Importers		
1	Germany	441
2	Iraq	264
3	Netherlands	190
4	China Hong Kong SAR	150
5	Singapore	96
6	Russian Federation	88
7	UAE	71
8	Mexico	63
9	France	60
10	Belgium	56
Exporters		
Rank	**Country**	**Thousand Metric Tons**
1	Netherlands	350
2	Turkey	289
3	Poland	235
4	USA	150
5	Germany	156
6	Malaysia	105
7	China, Mainland	99
8	Belgium	89
9	Spain	77
10	Belarus	45

Data from FAOStat.

Table 21.14 International trade of liquid eggs in 2016.

Importers			Exporters		
Rank	Country	Thousand Metric Tons	Rank	Country	Thousand Metric Tons
1	Germany	67	1	Netherlands	94
2	UK	46	2	Poland	24
3	France	31	3	Belgium	23
4	Belgium	23	4	Spain	23
5	Poland	24	5	France	17

Data from FAOStat.

within the single market of the European Union with easy (no custom posts) cross-border transportation.

There is marked international trade in liquid eggs (see Table 21.14). Germany is the number one importer of both liquid eggs and shelled eggs.

Trends in World Trade in Poultry

Marked changes in poultry imports and exports have occurred. With the competitive advantages of low-cost locally produced corn and soybeans, Brazil increased its exports 4.4-fold between 2000 and 2016 (Table 21.7). This is likely to continue. Argentina is becoming a significant exporter of poultry meat (exports in chicken meat increased 11-fold between 2000 and 2016). The United States also has a competitive advantage with an 11% increase in chicken meat exports between 2000 and 2016. Exports of poultry and eggs are also likely to increase. This is assuming that there are not artificial constraints to trade such as tariffs and/or regulations that are not science-based.

World Trade in Duck and Goose Meat

World trade in duck and goose meat is substantial, amounting to more than $1 billion (see Table 21.5) (compared to $300 million in 2000). This includes high-value products such as duck and goose liver for pâté de foie gras.

21.5 International Competitiveness

Competitiveness of the Poultry Industry in North and South America

The competitiveness of poultry production in North America stems from a number of factors including low cost, high-quality processed corn and soybeans for feed; infrastructure (roads, railroads, processing plants, supplies, etc.); a legal system with enforceable contracts and title to land; education for the labor force (schools, community colleges, and land-grant universities); technology and the research-extension base; efficient management and labor force in vertically integrated companies; the availability of capital for loans (developed banking system), and relatively low taxes and transparent regulatory environment with few corrupt government officials.

Argentina and Brazil also have the advantage of low-cost corn and soybeans. The loan deficiency payments for US corn and soy products increase production. This tends to lower prices and acts as an indirect subsidy for producers of poultry, eggs, and other livestock products. Competitive disadvantages for the United States, Canada, and Western Europe include the high cost of labor together with the costs of environmental and welfare regulations.

Competitiveness of the Poultry Industry in the European Union

The success of the poultry industry in the European Union stems from a number of factors including the common agricultural policy and other policies that restrict imports; consumer demand for specific products (compared to commodity products) including free-range and organic poultry and eggs; retailers supplying and promoting specific poultry products; and supply chains tightly linking producers with consumers.

Competitiveness of the Poultry Industry in Asia

The success of the poultry industry in Asia stems from a number of factors including strong government support; building on success; vertical integration; supply chains tightly linking producers with consumers; consumer demand for meat and an increasing middle class; and retailers supplying and promoting specific poultry products.

21.6 Vertical Coordination in the Egg Industry

Egg production is vertically coordinated with the following systems:

- Producer contracts (33%).
- Vertical integration (63%).
- Some marketing contracts (3%).

Producer contracts involve the contractor—who provides layers, feed, and other supplies. The grower provides labor, housing, and equipment. The eggs belong to the contractor and the grower is paid based on the number of eggs, with incentive payments. Vertical integration in the egg industry has been predominantly led by producers. They become integrators with ownership of laying hens and the facilities to produce them, feed mills, hatcheries, egg packing, and marketing. Cooperatives using marketing contracts represent about 3% of the industry. Growth for this sector for niche products is possible.

Cal-Maine Foods is the leading egg company in the United States. Cal-Maine produces about 80% of its eggs via full vertical integration with the remainder via production contracts. The company sells the eggs as shell or table eggs. Another major egg processor is Michael Foods. It employs a mix of production and marketing contracts. The company processes over 90% of eggs as further processed products (e.g., precooked omelets, reduced cholesterol products, etc.).

Advantages and Disadvantages of Vertical Coordination

The advantages of vertical coordination, particularly moving toward vertical integration, include a reduction in risk and uncertainties (compared with oscillation in prices on the spot market); increased profitability due to different points on the value/supply chain; increased access to capital at potentially lower interest rates (see Figure 18.8 for an example of the importance of capital); reduced transaction costs; quality control; improved management; improved efficiency through specialization and elimination of redundancy; discounts for bulk purchase; economies of scale allowing the use of new technology in production and processing, and hence even greater efficiencies; and the ability to trademark and obtain premiums.

It is said that a problem for farmers' profitability is that they "buy retail and sell wholesale" (many other successful businesses buy wholesale and sell retail). Greater vertical coordination leans more toward the prevailing system in business—"buy wholesale, sell retail."

Disadvantages of vertical coordination include reduced freedom and decision making for the grower; changes in the power structure of the grower-integrator relationship (while growers may experience a reduction in negotiating position, processors are experiencing a similar situation with retailers); and the long-term relationships between grower–processor–retailer require all to be profitable and expand, with the success of each being mutually advantageous.

Contracts

There are considerable advantages in contracts because they are legally enforceable. A poultry producer should read the agreement with care and consult a legal advisor to ensure that all of the terms are clearly spelled out and understood. A good contract must be clear, complete, and concise as to the duties and responsibilities of all parties. Actions for breach of contract and public laws (supported by each state's Attorney General) can protect growers. However, remember that successful long-term relationships are based on trust.

Specifics of the Contract

The following specifics should be included in the contract:

- The contract should be specific as to starting and ending dates per brood or time basis. A time contract usually specifies 4–6 broods per year.
- Each party should retain the same right for continuing or closing the program. This could minimize hardships for growers who have used credit in providing housing and equipment.
- Cancellation. This should be specific and clearly understood, with equal rights and privileges.
- Management. The contract should identify who is responsible for decisions; and details of the management program should be spelled out.
- Payment or settlement. The contract should be clear as to the method of computing rate, time, incentives, penalties, and losses including condemnation.
- Arbitration. There may be procedures providing for binding settlement to avoid court proceedings.
- Legal relationship of contracting parties. It should be clearly stated whether or not the contract is a partnership, employer–employee situation, or ar-

ranged on an independent basis. This is important for social security and income tax purposes.

21.7 Poultry Business Issues

Types of Business Organizations

There are three major types of business organizations: (1) sole proprietorship, (2) partnership, and (3) corporation.

Sole Proprietorship

Sole proprietorship is a business owned and operated by one individual. This is the most common type of business organization in US agriculture. Under this, one person controls the business, having sole management and control. This may be modified through contracts. The sole proprietors get all the profits or the losses. The two major limitations are that it may be more difficult to acquire new capital for expansion and not much can be done to provide for continuity with the passing of the owner.

Partnership

A **general partnership** is an association of two or more persons who, as co-owners, operate the business. About 13% of US farms are partnerships; most involve family members. For a partnership to be successful, the enterprise must be sufficiently large to utilize the abilities of the partners and to compensate them. A partnership has advantages including combining resources that can increase efficiency, equitable management, tax savings (a partnership does not pay any tax), and flexibility. Partnerships may have disadvantages, such as liability for debts, uncertainty of length of agreement, difficulty of determining value of a partner's interest, and limitations on management effectiveness.

A **limited partnership** is an arrangement in which two or more parties supply the capital (limited partner), but only one partner is involved in the management (general partner). The advantages include bringing in outside capital and limited liability. The disadvantages are that the general partner has unlimited liability and the limited partners have no voice in management.

Corporation

A corporation is a device for carrying out a farming enterprise as a legal entity entirely distinct from the persons who control it. It is restricted to doing only what is specified in its charter and must register in each state it does business in. Advantages include continuity, transfer of ownership, and limitation of the liability of shareholders to the value of their stock. A corporation may be family owned.

Corporate Structure of Integrators

Some integrators such as Tyson and Pilgrim's Pride are public (or publicly traded) companies. These are traded on a stock exchange and held to strict financial requirements. Others, such as Perdue Farms, are privately held.

Capital Needs and Debt

Farmers in the United States had an aggregate debt of about $350 billion in 2017, with about 80% equity in their business and 20% borrowed money (debt). However, growers have high debts. Poultry production is capital intensive. New or renovated broiler grow-out houses are usually debt-financed. Contract growers have an aggregate debt of over $5 billion, with the USDA's Farm Service Agency guaranteeing over $200 million. The contract (if long term), buildings, and equipment are used as collateral for the loans.

Definitions

Assets: tangible items of value. Examples include money, stocks, bonds, land, buildings, or a business.

Debts: moneys owed to banks and other lenders.

Equity: the net of assets minus debts.

Debt Repayment Capacity Utilization (DRCU): measures a farm's ability to repay its loans.

It is not surprising that according to the USDA's Economic Research Service, poultry producers have the highest debt-to-asset ratio compared to other sectors of agriculture in the US. In 2017, broiler growers had a debt-to-asset ratio of between 0.2–0.25 (about 22%) while all US farmers had a debt-to-asset ratio of 0.14.

The debt-to-asset ratio is smaller for small family grower farms than for large-scale family farms, with medium-scale family farms intermediate. An alternative way of expressing this is **debt repayment capacity utilization** (DRCU). DRCU measures the ability to repay the loan, with a DRCU of over 1.2 being a problem of repayment. The average DRCU for broiler growers is 0.7. Credit is an integral part of the grower's business and includes short-term loans (1 year or less) that are used for the purchase of supplies, etc.; intermediate-term loans (1–7 years) that are used for buying equipment or remodeling existing build-

Figure 21.4 Difficulties repaying major debt can result in worries and stresses for a relationship and family. (Source: WAYHOME studio/Shutterstock)

ings; and long-term loans (15–25 years) that are secured for new buildings and mortgage on real estate and to buy land.

Grain Inspection, Packers and Stockyards Administration (GIPSA) and Poultry Production

In the US, the relationship between broiler growers and processors is regulated by the USDA's Grain Inspection, Packers and Stockyards Administration (GIPSA) under the Packers and Stockyards Act of 1921 as amended multiple times. The Act defines a grower as someone raising poultry for slaughter by another; a poultry growing arrangement as any arrangement by which a grower cares for chickens following another's instructions (e.g., grow-out contracts and marketing agreements); and a packer as someone who buys livestock for sale.

Moreover, GIPSA and the Packers and Stockyards Act of 1921 enumerate a series of **unlawful practices** including use of any unfair, unjustly discriminatory, or deceptive practices; manipulating or controlling prices; or creating a monopoly. It also lists specific **requirements** for contracts between contract growers and processors; payment by processor (referred to as live poultry dealer) to grower by the fifteenth day following the week in which the poultry is slaughtered.

- Delay in payment is considered an "unfair practice" and hence a violation of this Act.

21.8 Business Planning, Standard Operating Procedures, Records, and Databases

Introduction

Examples of good business practices include planning for eventualities and having written standard operating procedures (SOPs). Other key systems are the keeping and reviewing of records, comparing your results with industry averages, budgeting, and financial planning. These systems are discussed below.

Records

The key to good business and management is records. Why keep records? The chief functions of records and accounts are (1) to provide information on which the management and business may be analyzed, with the strong and weak points ascertained (this assists for more effective planning); (2) to ultimately provide profit and loss statements; and (3) to increase net earnings through properly analyzing the records. These are essential to good management. Like any other business, today's successful poultry producers must have, and use, computerized records.

Databases

In the United States, the managers in the poultry industry have access to databases (e.g., the blue book from the Agri-Stat database) covering detailed comparison of production in chicken production units and complexes. This proprietary information allows comparison of an individual unit or its manager with others in the industry and with previous months and years. This is a tremendous tool to improve the quality of management and the efficiency of production.

Budgets

A budget is a projection of records and accounts and a plan for organizing and operating ahead for a specified period of time. A short-time budget is usually for 1 year, whereas a long-time budget is for a period of 3 to 5 years.

Enterprise Accounts

Where an enterprise is diversified, enterprise accounts should be kept—three different accounts for three different enterprises. They make it possible to determine which enterprises have been most profitable, and which least profitable; facilitate comparison of a given enterprise with competing enterprises of like kind; and allow determination of profitableness at the margin (the last unit of production). This will give an indication as to whether to increase the size of a certain enterprise.

Tax Management, Estate Planning, and Wills

Tax management and reporting consist of complying with the law but paying no more tax than required. The preparation of wills, trusts, and partnership agreements requires consideration of the effects of federal and state tax law. A will is a set of instructions drawn up by or for an individual that details how he or she wishes the estate to be handled after their death. Despite the importance of a will, many farmers die without one. Always consult a CPA and attorney in these activities.

Liability

Poultry producers, as well as livestock producers, are vulnerable to damage suits. Moreover, the number of damage suits arising each year is increasing at an alarming rate, with astronomical damages being claimed. Comprehensive personal liability insurance protects a producer who is sued for alleged damages suffered from an accident involving his or her property. Workers' compensation insurance and employers' liability insurance protect farmers against claims and court awards from injured employees.

Workers' Compensation

Workers' compensation laws are in force throughout the United States. These cover on-the-job injuries and protect disabled workers regardless of whether their disabilities are temporary or permanent. Workers' compensation provides employees with assured payment for medical expenses or lost income due to injury on the job. Producers should seek the advice of paid agricultural business consultants and insurance agents experienced in workers' compensation and liability insurance.

Social Security

In the United States, Social Security is a system of retirement, health, and disability payments with both employees (e.g., agricultural workers) and employers (e.g., poultry producers) paying in on a regular basis. Employers pay their contribution and deduct each employee's contribution from his or her paycheck. Employers report cash wages for each employee by January 31 of each year. Agricultural workers admitted to the United States on a temporary basis are not eligible.

21.9 Allied Poultry Industries

The poultry industry leans heavily on the support of allied industries. These include the following:

- The animal health industry, which includes manufacturers of drugs and vaccines (see Table 21.15).
- Feed and feed ingredient manufacturers.
- Poultry information services.
- Facility and equipment designers and manufacturers.
- Waste disposal engineering and systems.
- Food manufacturers who use so much poultry meat and eggs.
- Transportation companies (ranging from airlines carrying day-old chicks, to truckers carrying poultry and poultry products, to railroads carrying feed ingredients, to poultry-raising regions, to international ports and shipping moving poultry products for export).

Table 21.15 Top animal health companies in 2018.

Ranking	Company	Revenue (Billion $)
1	Zoetis[1]	5.8
2	Boehringer Ingelheim Animal Health	4.5
3	Merck Animal Health	4.2
4	Elanco (Eli Lilly)	3.14
5	IDEXX Laboratories	2.2
6	Bayer Animal Health	1.7
7	Ceva Santé Animale	1.2
8	Virbac S.A.	0.98
9	Vetoquinol S.A.	0.41

[1] Spun-out of Pfizer.

21.10 Poultry Research

Poultry-related research is conducted in universities, government laboratories, and in private industries (integrators, food industry, animal health and feed companies, equipment manufacturers). Research is contributing to the poultry industry in the following ways:

- Reduction in the cost of production due to improved growth rate and/or carcass yield or dressing percentage; decreased feed required to achieve a unit of meat or eggs and reduced cost of feed; improved facilities designed for optimal production and/or reducing capital requirements (lower-cost construction and/ or greater longevity); and automation to reduce labor costs, etc.

- Decreases in the impact of environmental factors such as heat stress and diseases on production.
- Increases in the variety of poultry products and their quality (eating properties)/healthfulness (nutritional and food safety characteristics).
- Improved meat quality with more high quality breast muscle.
- Science-based knowledge of the advantage and disadvantages of different production systems, such as organic production and free-range poultry or eggs.
- Improvements in the sustainability of the industry by addressing regulatory issues such as environmental problems, including the disposal of the carcasses of mortalities and animal waste, and welfare concerns—this being a regulatory, a consumer, and a social issue.

21.11 Marketing of Chicken Meat

Chicken meat is popular because of consumer perceptions of the low price, consistent quality product, healthful and low-fat meat, the availability of multiple products at retail, and fast-food units. Chicken meat comes from broiler chickens. The classes of chickens are summarized in Textbox 21D.

In the US, 25% of chickens are 4.25 lb (1.93 kg) or less, 33% are 4.26–6.25 lb (1.93–2.83 kg), 24% are 6.26–7.75 lb (2.83–3.52 kg), and 18% are more than 7.75 lb (> 3.52 kg). The dressing percentage for broiler chickens ranges from 70% to 80%. Of chickens produced in the United States, 48% are sold to retail outlets (supermarkets, etc.), 35% are sold to food services, such as fast-food restaurants (McDonald's has > 27,000 restaurants worldwide) and institutions (schools, hospitals, prisons), and 17% are exported. Increasingly, chickens in the US are processed prior to sale, with 10% sold as whole birds, 45% cut up, and 45% further processed (e.g., as nuggets—McNuggets®—and frozen meals).

Further processing includes mechanically deboned chicken meat. Ground chicken meat products in an emulsion include frankfurters. Drying is another step in further processing. Poultry meat can be dried (using hot air) as a method of preservation, to reduce weight, and/or to accommodate the food to which it is added. Perhaps the best example of dried chicken is in dried chicken soup mixes.

Textbox 21D

Classes for Chicken

USDA Classes for Poultry, Specifically Chickens

The updated poultry classes, specifically for chicken, according to the USDA are as follows:

- A **Rock Cornish game hen** or **Cornish game hen** is an immature chicken (male or female) that is less than 5 weeks old with a ready-to-cook carcass weight of 2 lb (0.45 kg) or less.
- A **broiler** or **fryer** is a young chicken (male or female) less than 10 weeks old and with a carcass weight of between 2 lb (0.45 kg) and 5 lb (2.3 kg).
- A **roaster** or **roasting chicken** is a young chicken (male or female) aged between 8–12 weeks old with a ready-to-cook carcass weight of 5 lb (2.3 kg) or more.
- A **capon** is a surgically castrated male chicken less than 4 months old.

Industry Used Classification of Live Chickens for Different Markets

The market for chicken is segmented in the following manner by weight.

- < 3 lb (1.36 kg) Cornish game hen or Cornish hen or Rock Cornish hen—sold as dressed whole bird.
- < 5.25 lb (2.38 kg) broiler chicken for the deli market, rotisserie chicken, or fast food chicken (e.g., KFC and Popeyes).
- 5.25 lb (2.38 kg) broiler chicken for fresh markets/grocery stores as whole dressed chicken or chicken parts.
- 6.5–10 lb (2.95–4.54 kg) larger birds are used today due to consumer demand for white meat as larger birds have a higher (percentage) breast yield. This is particularly important as integrators are paid on the percentage of breast meat. In addition, processing costs per bird are similar with size but are lower per unit breast muscle in larger chickens. Large birds are generally deboned, further processed, and can be portion controlled. Examples include chicken tenders, chicken for grilled or fried chicken sandwiches, and chicken nuggets (from breast trim).

21.12 Impact of Quick-Service Restaurants

Large amounts of chicken meat are purchased by restaurants, including quick-service (also known as fast food restaurants) and takeout restaurants. For example, KFC is a major destination for chicken.

Large restaurant chains where chicken is a major part of the menu include Subway (about 44,834 restaurants worldwide), McDonald's (about 37,241 locations worldwide), KFC (about 21,487 locations worldwide), Burger King (16,717 locations worldwide), Popeyes (2,600 locations worldwide), Chick-fil-A (about 2,200 locations worldwide), and Church's Chicken (about 1,700 locations worldwide). These restaurants serve a large array of menu items using chicken and eggs, including rotisserie-style chicken (Subway), McChicken® and McMuffin® sandwiches (McDonald's), fried chicken (e.g., KFC), chicken fries (e.g., Burger King), chicken tenders (e.g., Popeyes), chicken sandwiches (e.g., Chick-fil-A), and chicken strips (e.g., Church's Chicken).

Factoid on Chicken Wings

It is estimated that 1.3 billion chicken wings are eaten in the United States on Super Bowl Sunday.

The Impact of McDonald's on the Poultry Industry

McDonald's is impacting broiler chicken production as a very major purchaser of eggs. In 2015, the company announced that McNuggets® and other chicken dishes served at their locations are now from antibiotic-free chickens. In addition, McNuggets® are now also free of artificial preservatives. When such a major user of poultry meat makes such a shift, it can represent a "tipping point" for specific management practices in broiler production in its entirety.

As a major purchaser of eggs, McDonald's has a large impact on egg production. In 2015, for example, McDonald's announced that they would begin a transition to using eggs only from cage-free hens. It could take as long as 10 years to reach the goal.

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22

Ducks and Geese

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Know how many ducks and geese are produced globally and from which major countries.
2. Give an example of a dish that includes duck.
3. List the major breed of ducks used?
4. Know the compositions of ducks and goose meat, liver, and eggs.
5. List several breeds for ducks and geese.
6. Know the origins of ducks and geese.
7. Briefly describe the production practices associated with these types of poultry.
8. List diseases important in duck production.
9. Know what poultry diseases are not important with ducks.
10. Know what vaccinations are carried out.
11. List the countries in which duck production is far more important than in the United States.
12. Know if duck feed includes antibiotics and/or hormones to increase growth.
13. Know if geese are raised on pasture.
14. List what geese eat.

22.1 Overview of Global Production of Ducks and Goose Meat, Eggs, and Feathers

On a global basis, the production of duck, goose, and guinea fowl for meat is important. The aggregate world production of duck, goose, and guinea fowl meat together exceeds the world production of turkey meat. According to the United Nations Food and Agriculture Organization (FAO), global production of duck, goose, and guinea fowl meat exceeded that of turkey in 2017. Duck, goose, and guinea fowl totaled more than 7.0 million metric tons (for data separating out ducks see Table 22.1) and turkey totaled more than 5.6 million metric tons. The terms used for the external anatomy of the domestic duck are shown in the Figure 22.1 below.

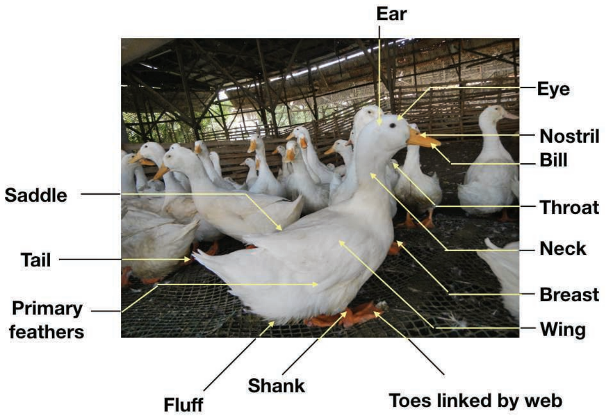


Figure 22.1 The anatomy of a duck.

Figure 22.2 Roast duck. (Source: teleginatania/Shutterstock)

There is significant production of duck and goose eggs (referred to as birds other than chickens by FAO), again principally in China. In 2017, global production totaled more than 6.9 million metric tons, of which over 5.5 million metric tons was from China.

Duck and goose feathers are used for insulation in winter clothes, for comforters (e.g., eiderdown), and pillows. Down, the small fluffy feathers without a shaft, are used in winter clothes and bedding (particularly the higher-priced quality products). They are used as insulation and for comfort. The air-filled down feathers make up 10% of the total number of feathers in ducks and geese and are located under the other plumage. They provide thermal protection. When feathers are sold as down, the product must be more than 80% down and less than 20% feathers. Feathers are washed (5–8 times) in soap to eliminate animal waste, but some oils should be left attached.

Figure 22.3 Pekin roast duck. (Source: vsl/Shutterstock)

22.2 Introduction to Ducks

Domesticated ducks are versatile and can live under a wide range of climatic conditions. Duck meat is relatively high in fat and dishes made with duck meat are popular with many lovers of good food (see Figures 22.2 through 22.4).

Examples of dishes include cooked and smoked meats such as duck sausage, duck bacon, and duck meatballs; Pekin duck (a Chinese dish with thinly sliced duck prepared with crunchy skin and served with scallions, sweet bean sauce, and small thin "pancakes"); roast duck; duck breast; foie gras (the fatty liver of force-fed ducks or geese) or foie gras pâté; ter-

Figure 22.4 Roast duck breast with cherry pomegranate sauce. (Source: Spring song/Shutterstock)

rines and mousse; duck confit (meat roasted with herbs and possibly citrus fruit); duck fat; and cured duck gizzards in salads.

Some duck dishes are plays on words associated with ducks, for instance "Quacker Jacks" (duck bacon, popcorn, and peanuts) and "plum ducky" (a dish with duck and plums). The feet and tongues of ducks and geese are considered delicacies in East Asia, and US-produced feet and tongues are exported to Asian cities such as Hong Kong.

22.3 Global Production of Ducks

Global production of ducks is up 22.2% in 10 years (Table 22.1). China is by far the principal producer of duck meat in the world, producing 63% of global production. Production in China is also increasing with production up 32.9% in 10 years. Other major producers of duck meat include France and Myanmar (see Table 22.1).

Table 22.1 Global production of ducks in 2007 and 2017.

	Production in Thousand Metric Tons	
Country and Rank	**2007**	**2017**
1. China	2,308	3,067
2. France	290	235
3. Myanmar	74	152
4. Vietnam	74	132
5. Malaysia	132	76
6. Republic of Korea	57	71
7. Egypt	65	64
8. USA	60	60
9. Thailand	85	59
10. Hungary	50	53
World	**3,649**	**4,460**

22.4 Duck Production in the United States

About 30 million ducks are marketed in the United States each year. Duck production was once centered on Long Island, New York, but now the top states producing ducks are Indiana (where the headquarters of Maple Leaf Farms is located), California, and Pennsylvania. The largest producer of ducks in North America is Maple Leaf Farms, producing 15 million ducks per year. Large producers of ducks in Europe include Cherry Valley Farms (UK).

22.5 Domestication and Development of Ducks

The domestic duck originated from the Mallard duck (*Anas platyrhynchos*) (Figure 22.5). The Mallard is found across Europe and Asia. There is disagreement on where ducks were domesticated. It has been speculated that Mallard ducks were separately domesticated in East Asia, leading to the Asian breeds (e.g., the Pekin) and close to Europe (in the Fertile Crescent), leading to the European breeds (e.g., the Rouen and Aylesbury).

White Pekin ducks (see Figure 22.1) were introduced to the United States from China in 1873. Production of ducks in the US was initially focused in Long Island (New York), however as land became prohibitively expensive, it moved out. The industry is now focused in the Midwest.

The Muscovy was domesticated in South America, perhaps during the pre-Inca period in Colombia or Peru, well before contact with Europeans from 1492 onward. Muscovies (Figure 22.6) were transported to Europe and Africa and later to Asia. The wild species of Muscovy is a waterfowl that is unusual because it is a perching bird. Its range is the South American rainforest.

Figure 22.5 Adult mallard or wild duck (*Anasplatyrhynchos*). (Source: meunierd/Shutterstock)

TEXTBOX 22A

Factoids about Ducks

1. Duck definitions

- Adult male duck: Drake.
- Adult female duck: Duck (see Textbox 22A Figure 1).
- Young duck: Duckling (see Textbox 22A Figure 2).

2. What is a mulard?

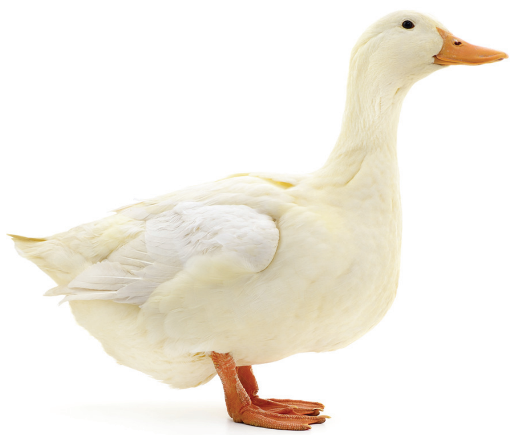
Mulards (also known as moulards or mule ducks) are crosses usually between female domestic ducks (*Anas platyrhynchos*) and male Muscovies (*Cairina moschata*) (see Textbox 22A Figure 3). These interspecies (intergenera) hybrids are sterile (unable to produce offspring) but exhibit hybrid vigor. They are produced commercially in Asia, North America, and Europe.

3. Maple Leaf Farms (MLF)

Maple Leaf Farms is a vertically integrated producer of ducks. The company breeds its own ducks; has hatcheries, feed mills, and feather operations; as well as primary and further processing operations. The company works with growers (partner farmers) and provides assurances about both food safety and animal welfare.

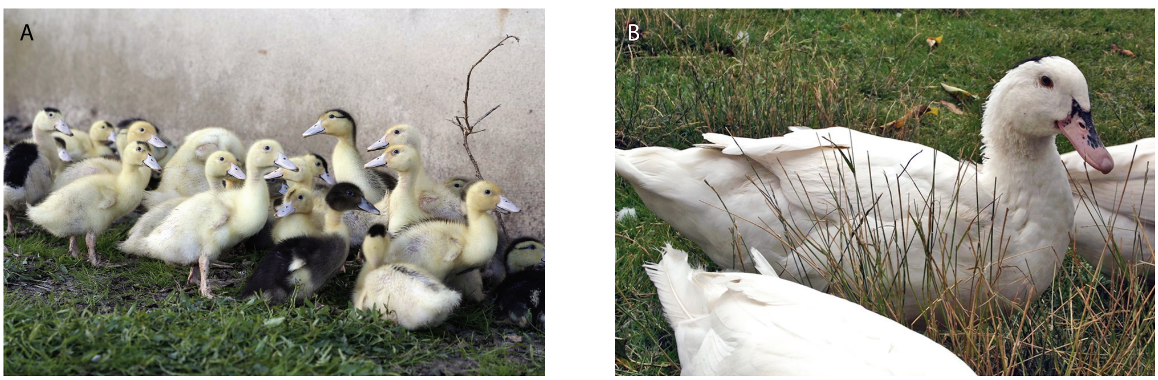
4. Donald Duck

Donald Duck is one of the earliest and most popular cartoon characters created by Walt Disney. The first movie with this anthropomorphized duck was released in 1934. He has appeared in multiple movies—some with his "love" interest, Daisy Duck, and his nephews Huey, Dewey, and Louie Duck.



Textbox 22A Figure 1 Domesticated duck. (Source: Tsekhmister/Stutterstock.com)

Textbox 22A Figure 2 Domesticated duckling. (Source: Tsekhmister/ Stutterstock.com)



Textbox 22A Figure 3 (A) Mulard ducklings. (Source: Ethique & Animaux/Wikimedia Commons) (B) Mulards. (Source: Atlasroutier/Wikimedia Commons)

A. Muscovy drake. (Source: gnuckx/Wikimedia Commons)

B. Pair of Muscovies. (Source: MrPanyGoff/Wikimedia Commons)

Figure 22.6 Muscovies or Muscovy ducks (*Cairina moschata)*.

Duck Classification

Ducks are classified as follows:

Phylum: *Chordata*
Subphylum: *Vertebrata*
Class: *Aves*
- Infraclass: *Neognathae*
- Superorder: *Galloanserae*

Order: *Anseriformes.*
Species: *Anas platyrhynchos* (mallard and domestic duck); *Cairina moschata* (Muscovy)

Domestic ducks are either in the species *Anas platyrhynchos* (domestic ducks and mallard ducks—see Figures 22.1 and 22.5) or *Cairina moschata* (Muscovy "ducks"). Domestic ducks have been referred to in the past as *Anas domesticus.* While Muscovies are sometimes referred to as a breed of duck, they are in fact a separate genus and species. Strictly speaking, they should be referred to as duck-like rather than ducks. For the purpose of convenience, ducks and Muscovies will be considered together.

22.6 Duck Meat

Duck meat is relatively high in fat (see Table 22.2). Types of duck produced in the United States include broiler duckling or fryer duckling (this is a young duck that is < 8 weeks old and weighs between 3–6.5 lb or 1.4–2.9 kg), roaster duckling (this is a young duck that is < 16 weeks old and weighs between 4–7.5 lb or 1.8–3.4 kg), and mature or old duck (this is > 6 months old and is used for processed duck).

Cooking Duck

1. Is the meat of duck and goose red or white?

According to the USDA, both duck and goose meat are considered white meat. This is despite the darker color of the breast muscles. The breast muscles are darker because of the presence of the protein myoglobin. This stores oxygen for flight. There is also a higher blood flow, and hence hemoglobin, in duck and geese breasts than in chickens.

2. Is pink duck or goose safe?

Cooked duck or goose can be pink. The USDA considers it safe to eat as long at the internal temperature is at least 165°F (74°C).

The broiler and roaster ducklings have tender meat while mature ducks have tougher meat. The dressing percentage (carcass weight as a percentage of the body weight) for Pekin ducks is 58%. Ducks are usually sold frozen but fresh duck can be available at specialized stores or around holiday seasons. It is essential that frozen ducks are completely thawed (in a refrigerator) before cooking. This reduces the multiplication of pathogenic bacteria (such as *Salmonella*) that can occur in the "danger zone" between 40° and 140°F (4.5–60°C) and, thereby, promotes the safety of the food.

Table 22.2 Composition of raw duck and goose meat, liver, fat, and eggs with comparisons with chicken (per 100 g or 3.5 oz).

	Water (g or %)	Energy (kcal)	Protein (g or %)	Fat (g or %)
Raw Duck with Skin	48.5	404	11.5	39.3
Raw Duck	73.8	135	18.3	5.9
Raw Goose with Skin	49.7	371	15.9	33.6
Raw Goose	68.3	161	22.7	7.1
Raw Chicken White Meat	74.3	109	22.2	1.63
Duck Liver	71.8	136	18.7	4.6
Chicken Liver	76.4	119	16.9	4.8

Data from the USDA National Nutrient Database.

In the US, ducks at processing plants must be either inspected federally or by state agencies. According to the USDA, "USDA Grade A ducklings are the highest quality available. They have a plump and meaty appearance with no cuts, bruises, or tears on the skin. They also have no broken bones, no missing parts, and few pin feathers." Grade B and Grade C ducklings are generally not sold in grocery stores, rather they are further processed.

There are substantial amounts of fat under the skin in ducks (Table 22.3); considerably more than in chickens. This fat is mainly in the form of triglyceride in the subcutaneous adipose tissue. It is thought that the subcutaneous fat provides good insulation for ducks to prevent heat loss when swimming. When cooking ducks, it is recommended that the skin be pricked so the fats can run out. The subcutaneous fat gives roast duck its juiciness and allows the skin to be crispy. As in chickens and turkeys, there is very little adipose tissue in the muscles with the muscles not being marbled.

A Deeper Dive: Subcutaneous Fat in Ducks

In post-hatching, fatty acids are predominantly synthesized in the liver. They are transported to the developing abdominal and subcutaneous adipose tissue chiefly as either triglyceride or (triacylglycerol TG) or bound to very low density lipoproteins (Ding et al., 2012). The development of the subcutaneous adipose tissue is due to hyperplasia (increases in adipocyte numbers) and hypertrophy (increases in the size of the adipose cells) of the adipocytes until 4 weeks old. After 4 weeks of age, growth of the subcutaneous adipose tissue is due to hypertrophy (Evans et al., 1972; Kou et al., 2012). There are multiple factors influencing fat deposition, including ghrelin acting via the GH secretagogue receptor (Nie et al., 2009).

Duck liver and fat are also used in cooking. The composition of these is shown in Table 22.2. Duck liver can be served cooked and serviced, for instance, as a finely ground spreadable pâté. Pâté can be served cold, say as part of a charcuterie platter to spread on crackers, or hot. A specialty is foie gras. This is from the fatty liver from force-fed ducks or geese. It can be served as pâté de foie gras, as a mousse, or poached.

22.7 Duck Eggs

While there is little demand for duck eggs in the United States, there are significant markets in both Europe and Asia (see introduction section above). The composition of duck eggs is shown in Table 22.3. Duck eggs have a similar composition to chicken eggs but proportionately more yolk and hence more lipid, calcium, and energy.

22.8 Duck Breeds

Duck breeds are classified as either meat producers or egg producers. The Pekin duck is by far the predominant breed of duck for commercial production worldwide. White Pekin and Aylesbury ducks, together with Muscovies, are good meat breeds. Rouen, Cayuga, Swedish, and Call ducks reach weights that would make them valuable as meat producers, but their poor egg production and colored plumage make them less satisfactory for commercial production. Khaki Campbell and Indian Runners are very good egg-laying breeds, being the number one and number two egg producers per year, respectively. Where specialty duck egg markets exist, either breed would be a good choice.

Table 22.3 Comparison of the composition of eggs from ducks and chickens.

Egg Type	Water (g or %)	Energy (kcal)	Protein (g or %)	Fat (g or %)
Duck	70.3	185	12.8	13.8
Goose	70.4	185	13.8	13.3
Chicken	76.1	143	12.6	9.5

Data from the USDA National Nutrient Database.

22.9 Duck Breeding

The breeding and improvement of ducks has received less attention than the breeding of chickens and turkeys, reflecting their lesser economic importance in North America and Western Europe. Duck breeding in the United States is largely confined to breeding for meat production, with selection for more rapid and efficient gains, more lean meat, and higher egg production and hatchability.

Breeding Programs for Large-Scale Production

The growth of duck production, particularly in Asia, stems in part from genetic improvement. Breeding programs are making rapid progress in a manner analogous to that of chickens and turkeys. Cherry Valley Farms (UK) is a major source of breeding stock.

Care of Breeders

Birds can be brought into full production at about 7 months of age by providing a long day length (14 hours of light daily) (Figure 22.7).

Incubation

Duck eggs and Muscovy eggs require 28 and 35 days of incubation, respectively. Incubators designed for hatching duck eggs are available. On large commercial farms, ducklings are frequently taken from the machines as they hatch. However, great care must be taken to prevent chilling of newly hatched ducklings. It may be wise for small producers to keep the machine closed until hatching is completed.

Brooding and Rearing

Ducklings should be moved from the hatcher to comfortable brooding quarters as quickly as possible. Prevent chilling and do not overcrowd the birds during transit. Provide feed and water for ducklings as soon as they are placed in the brooder. Buildings of practically any type can be used to brood ducklings as long as the birds are kept warm, dry, and free of drafts. Ventilation systems and windows should be designed so that fresh air can be brought into the building without chilling the ducklings. Litter flooring may be used with chopped straw, wood shavings, and peat moss. Ducklings need supplementary heat for about 4 weeks after they hatch and clean drinking water at all times. Water may be supplied in hand-filled water fountains or by automatic waterers.

Figure 22.7 Ducklings in a nursery showing wire (A and B) and litter (C) floors together with waterers and feeders. (Photos kindly provided by Professor Gregory Fraley, Hope College, MI, with permission from Maple Leaf Farms)

22.10 Duck Feeding and Management

Ducks respond to management (good management = success, poor management = trouble). Ducks are raised indoors. Both breeder and market ducks lend themselves to environmentally controlled buildings and automation (see Figure 22.8). They must have water available for drinking and preening. Specific management requirements are summarized in Table 22.4.

Maximum efficiency for growth and reproduction can be obtained by using commercially prepared diets in the form of pellets. Duck feed in the United States is predominantly corn and soybean-based, together with vitamins and minerals, and most do not contain animal by-products. Subtherapeutic antibiotics are not used as growth promotants in duck production. Moreover, hormones are not allowed. Four diets are recommended: starter, grower, finisher, and breeder (see Chapter 7 for details).

Table 22.4 Specific issues for raising ducks.[1]

Water Requirement	a. Ducks have a much higher requirement for water for drinking than do chickens. b. There are risks of bacterial contamination of open waterers (troughs or bell-style). This can adversely affect the health of the ducks. The best waterer systems are pin-metered water lines.
Environmental Temperature	a. The thermoneutral zone for ducks is 10–13°C (50–55°F). b. Ducks are more sensitive to elevated temperatures (or (> 24°C or > 75°F) than chickens.
Flooring	a. Bedding can be pine shavings, saw dust, straw, etc. b. It must be clean and dry. c. It is recommended that new bedding be added daily.
Caging	As ducks are social birds, individual caging should be avoided.
Euthanasia	The neck of ducks is both strong and long and, thus, cervical dislocation should not be employed. Decapitation is acceptable.

[1] The input of Gregory Fraley (Hope College, MI) is gratefully acknowledged.

Figure 22.8 Breeding ducks showing (A) litter floor and (B) curtain openings to outside together with (C) feeders (left) and waterers (right). (Photos kindly provided by Professor Gregory Fraley, Hope College, MI, with permission from Maple Leaf Farms.)

Textbox 22B

A Deeper Dive: Small Scale Production of Ducks in Asia

There are about 60 million ducks in Vietnam, with over 95% raised in small-scale family systems (FAO, 2006a). In Indonesia there are over 30 million ducks, also raised in small-scale operations. Duck production can be categorized under the following broad headings:

1. Scavenging free-range herding systems connected with rice production (see Figures 22B.1 and 22B.2).
2. Semi-intensive systems including ducks on a dedicated pond and integrated duck production systems (employing integration such as rice-fish-duck with a pond or fish-duck-pigs) (see Textbox 22B figure 3).
3. Confined systems (but not at level of commercialized).

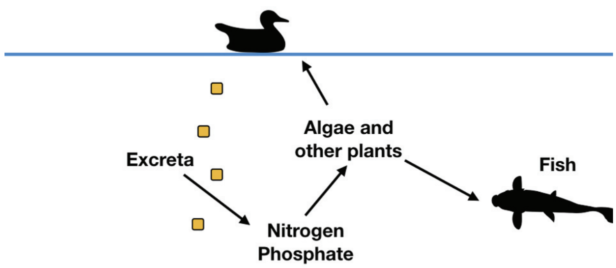
In Vietnam, duck production uses local breeds. In Indonesia, ducks being raised are also predominantly local breeds of domesticated ducks (*Anas platyrhynchos*) together with Tegal ducks (formerly *Anas javanica* but presently known as *Dendrocygna javanica*) and imported Muscovy ducks (*Cairina moschata*). In Indonesia, the majority of farmers employ the semi-intense system (FAO, 2006b).

Integrating raising ducks with freshwater aquaculture has advantages. These systems not only result in the production of duck meat and/or eggs but also there is improved growth rates and feed/protein conversion rates of the aquaculture fish (common carp, grey mullet, silver carp, and tilapia) (e.g., Edwards et al., 1988; Essa et al., 1988; Mukherjee et al., 2004; Soliman et al., 2000). The integrated ponds have increased concentrations of ammonia, phosphate, and nitrate leading to increased natural productivity (i.e., growth) of both phytoplankton and zooplankton. In turn, the fish consume the algae and zooplankton (Mukherjee et al., 2004; Soliman et al., 2000) (see Textbox 22B Figure 3).

Ducks in the scavenger system and unvaccinated birds in the semi-intensive system are a reservoir for poultry diseases such as avian influenza (FAO, 2006b).

Textbox 22B Figure 1 A small flock of domestic ducks herded on a small river (forefront) with a herd of cattle (middle view) in Vietnam. Ducks are a valued part of both traditional and commercial agriculture, particularly in Asia. (Source: xuanhuongho/Shutterstock)

Textbox 22B Figure 2 Rice production on terraced paddy field in Thailand. Traditionally, ducks are part of an integrated system tied to rice production in Southeast Asia. (Source: Travel mania/Shutterstock)



Textbox 22B Figure 3 Integrated duck and fish production.

22.11 Duck Diseases and Health

Ducks are free from such common poultry diseases as leukosis, Marek's disease, and infectious bronchitis. On large commercial duck farms, the risk of disease can be minimized by (1) a closed flock policy and (2) a biosecurity policy including controls on the entry of vehicles and visitors. In case of disease, consult with a veterinarian. Examples of diseases follow.

- **Anatipestifer disease** (also known as new duck syndrome or duck septicaemia) is one of the most serious diseases affecting ducklings, with losses up to 75%. It is a bacterial disease caused by the gram negative bacteria *Riemerella anatipestifer*. Symptoms resemble those of chronic respiratory disease of chickens. The first signs of the disease are sneezing and loss of balance. Afflicted ducklings fall over on their sides and backs. The mortality for this disease ranges from 2 to 75%. Vaccination is recommended (see below).
- **Botulism** occurs in both young and adult ducks. It is caused by the bacterium *Clostridium botulinum*, which grows in decaying organic material. Ducks ingesting toxins produced by the bacteria lose control of their neck muscles. Maintaining clean facilities will prevent this disease.
- **Coccidiosis** is not as severe as in chickens. It can cause mortality and morbidity and, hence, poor performance. The causal organism in ducks is different from that in chickens.
- **Duck virus enteritis** (duck plague) is an acute viral disease affecting ducks and geese. It is transmissible by contact, swimming water, and from migratory waterfowl. Symptoms include watery diarrhea and nasal discharge. General droopiness develops in about 5 days after exposure. Symptoms last for 3 to 4 days, frequently ending in death. Postmortem examination shows multiple hemorrhages in body organs. Strict sanitation will help control the disease. A modified chicken embryo-adapted vaccine has been developed and used successfully.
- **Fowl cholera** can cause high mortality but strict sanitation will help control it. Burn or bury dead birds. Vaccines can control losses from fowl cholera.
- **Necrotic enteritis**, caused by *C. perfringens*, is found in breeding stock. Breeder houses and yards must be free of wet litter. Mortality may be sporadic over a long period of time. Some antibiotics are effective for treatment and prevention.
- **Reproductive disorders**. Paralysis of the intromittent organ of drakes can be observed early in the mating season. Females can have prolapse of the vagina, impacted oviducts, and egg yolk peritonitis. The birds rendered incapable of reproduction should be culled.
- **Viral hepatitis** outbreaks can cause 80 to 90% mortality in flocks of ducklings (1–5 weeks old). This highly contagious disease strikes swiftly without warning. Vaccination may be recommended against duck viral hepatitis.
- **Brooder pneumonia** is caused by fungi in the litter. Good litter and a dry brooder house help prevent it.

Vaccination

Ducks are vaccinated against *Riemerella anatipestifer*. These gram negative bacteria are the causative agents for Anatipestifer disease (also known as new duck syndrome or duck septicemia).

22.12 Processing and Marketing Ducks

Feed should be withheld from the birds 8 to 10 hours before slaughter, but water may be provided up to the time of killing. Clean, uncrowded rearing facilities will help to prevent bruising, cutting, and other factors that cause poor product. Ducklings can be transported in crates or trailers to the slaughterhouse.

In large commercial slaughterhouses, ducklings are dipped through a molten wax after slaughtering. The wax hardens after immersion in cold water. It can then be peeled free to remove any feathers that remain. Wax can be reused if it is remelted and the feathers are screened out. Birds are then eviscerated and thoroughly washed. If birds are to be marketed frozen, package them in shrinkable plastic bags. There is further processing of duck.

The federal grades of ducks are USDA Grade A, Grade B, and Grade C and are essentially the same for all poultry (see Chapter 17). The grading program is voluntary. Grade B and C ducks are used for further processing.

22.13 Introduction to Geese

The FAO combines data for production of goose and guinea fowl. Chinese production of goose and guinea fowl dominate global production with 95.4% of global production in 2017; this reflecting production of geese (see Figure 22.9). Other major producers of goose meat include Poland, Hungary, Madagascar, and Egypt (see Table 22.5). There is little production of goose meat in the United States.

Goose Definitions

Gander: Adult male goose
Goose: Adult female goose
Gosling: Young goose

Types of geese produced in the United States include goslings (~8 lb or 3.6 kg), young goose (12–14 lb or 5.4–6.4 kg), mature or old goose (usually a spent breeder or old female with the meat used for processed goose), and gander (used for processed goose).

Figure 22.9 Domestic geese. (Source: igorstevanovic/ Shutterstock)

Table 22.5 Global production of goose and guinea fowl in 2007 and 2017.

	Production in Thousand Metric Tons	
Country and Rank	**2007**	**2017**
1. China	2,135	2,405
2. Poland	18	26
3. Egypt	20	24
4. Hungary	27	21
5. Madagascar	13	13
World	**2,246**	**2,522**

Data from FAOStat.

Geese are very hardy and can live almost entirely on good pasture. Yet, the production of geese for meat purposes does not enjoy the popularity in the United States that it has in some European and Asian countries. Over 300,000 geese are marketed each year in the US. The top goose producing states are California and South Dakota. In the United States, the number of farms selling geese has decreased. In addition, geese can be raised as a hobby for ornamental and exhibition purposes. Geese are less susceptible than chickens to many poultry diseases.

Canada geese (*Branta canadensis*) will not be considered even though they are a common wild goose of North America. There are major restrictions on hunting or holding Canada geese in the United States. Before Canada geese can be sold or transferred to another person, a permit must be obtained from the United States Fish and Wildlife Service (Department of the Interior).

22.14 Domestication

The North American and European breeds and Asian and African breeds of domestic geese were domesticated from different species of waterfowl and in different geographical locations. The North American and European breeds are descendants of the greylag goose, while Asian and African breeds are descendants of the swan goose. Domestication of geese occurred at least 5,000 years ago, independently in or close to the Fertile Crescent (probably in Egypt) and in China. This is analogous to the domestication of pigs with both a Middle East and East Asian domestication of different populations of Eurasian wild boars.

Classification of Geese

Geese are classified as follows:

Phylum: *Chordata*
Subphylum: *Vertebrata*
Class: *Aves*
Infraclass: *Neognathae*
Superorder: *Galloanserae*
Order: *Anseriformes*
Species: *Anser censer* (North American and European breeds of domestic geese); *Anser cygnoides* (Asian and African breeds of domestic geese)

22.15 Goose Meat

Goose (either sex) is sold as either young or mature goose. The young goose has tender meat. In the mature goose, the meat is tougher. Young geese are marketed at 12 to 16 weeks old, with a dressed weight of 11 lb (5 kg). The composition of uncooked dressed young goose is summarized in Table 22.2. Much of the fat is under the skin, and removal of the skin reduces fat to 7%. Figure 22.10 shows a cooked goose. Goose was a meat of choice for holiday meals.

Figure 22.10 Roast goose with vegetables prepared for Christmas dinner. (Source: Photocrea/Shutterstock)

22.16 Breeds of Geese

The breeding and improvement of geese in North America has received far less attention than in Europe and Asia. Toulouse, Emden, and African geese are heavy breeds. These are the most popular breeds in the United States for meat production. Other common breeds are Chinese, Buff, Pilgrim, Sebastopol, and Egyptian. There are considerable differences in breeds of geese. In choosing a breed, therefore, one should consider the purpose for which they are to be used. Geese are raised for meat and/or eggs, as show birds, or even guard animals. When choosing a breed, one should determine the market requirements, such as size (market body weight) and plumage color (white is generally preferred). Strains that lay the most eggs produce goslings at the lowest cost. For more details on goose breeds see Appendix I and, specifically, Appendix I Figure 9.

22.17 Incubation

Eggs should be washed soon after gathering. Store eggs at 55°F and a relative humidity of 75% until set for hatching. If eggs are held for more than a couple of days, turn them daily to increase the percentage of hatch. Hatchability decreases fairly rapidly after a 6 to 7-day holding period. Eggs properly stored can be held 10 to 14 days with fair results. The incubation period for most goose eggs is 29 to 31 days. For the Egyptian goose it is 35 days.

Incubators, either still-air or forced-draft, can be used to hatch goose eggs. However, artificial incubation of goose eggs is much more difficult than with chicken eggs because more time and higher humidity are required.

22.18 Goose Feeding and Management

Commercially, geese are usually raised indoors until 6 weeks of age. Goslings should have drinking water and feed when they are started under the brooder. For the first 3 weeks, feed goslings 20 to 22% protein goose starter pellets. After 3 weeks, feed 15% protein goose grower pellets. There is then a transition to pasture and the birds are completely on pasture between weeks 14 and 20 weeks where they eat vegetation together with supplementary grain. Geese can go on pasture as early as the first week, but they will only receive significant nutrition from 5 to 6 weeks of age. This may be provided by silage. According to the USDA, "geese are very selective and tend to pick out the palatable forages. They will reject alfalfa and narrow-leaved tough grasses and select the more succulent clovers and grasses. Geese cannot be raised satisfactorily on dried-out, mature pasture" (USDA, 1979). Suitable stocking densities are 20 to 40 birds per acre (~75 birds per hectare) depending on the size of the geese and the quality of the pasture.

Management

Breeder geese should be fed a pelleted breeder ration at least a month before egg production is desired. They do much better and waste less feed on pellets than on mash. A chicken-breeder ration may be used if special feeds for geese are not available. Provide oyster shells (or other calcium sources), grit, and plenty of clean, fresh drinking water at all times. Lights in the breeder house can be used to stimulate earlier egg production.

Diseases

Geese are resistant to diseases. If there are signs of disease, a poultry pathologist should be consulted immediately (also see Chapter 13).

22.19 Processing and Marketing Geese

Following slaughter, geese can be scalded in a commercial scalder. Water temperature should be 145–155°F (~66°C) and the length of the scald should be from 1.5 to 3 minutes. Detergent should be added to the water to hasten thorough wetting of the feathers. After scalding, the birds may be "rough-picked" by hand, picked on some type of conventional rubber-fingered picking machine, or placed in a spinner-type picker. After "rough-picking," it is difficult to remove the remaining pinfeathers and down. Because of the difficulty of handpicking, it is common practice to finish the "rough-picked" birds by dipping each bird in melted, specially formulated wax.

In large-scale operations, the birds are waxed in an on-the-line process with a wax temperature of 140–220°F (60–100°C). After waxing, the birds are exposed to a cold water spray or dipped in a tank of cold water to cool and harden the wax to a "tacky" state. The wax is then removed by hand, resulting in a clean, attractive carcass. The wax is reused by melting and straining out the feathers, pins, and so forth.

The US standards of quality are essentially the same for all poultry. Geese are graded for conformation, fleshing, and fattening. Defects, such as missing skin and bruises, are also considered in establishing quality.

22.20 Goose Feathers

Goose feathers are valuable for the bedding and clothing industries due to their properties (see the discussion on down feathers above).

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23

Exotic Poultry

CHAPTER SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Define the term ratite.
2. Know where ostriches, emu, and rhea are from.
3. Know when ratites were domesticated.
4. Know how ostriches, emus, and rhea are similar.
5. Know what ostriches are used for.
6. Know what emus are used for.
7. Know the compositions of ostrich, emu, pigeon, guinea fowl, quail, and pheasant meat.
8. Know the composition of quail eggs and how they compare to chicken eggs.
9. Know where guinea fowl were domesticated.
10. Know how long ostrich, emu, and quail eggs should be incubated.
11. Know how guinea fowl production can be increased in Africa.
12. Explain the advantages and disadvantages of rearing guinea fowl in backyards in the US.

23.1 INTRODUCTION

The goal of this chapter is to provide insight into exotic poultry, including ostriches, emus, pigeons, guinea fowl, quail, pheasants, partridges, and peafowl.

23.2 OVERVIEW OF RATITES (OSTRICHES, EMUS, AND RHEAS)

Ratites (walking birds) are flightless herbivorous birds that include, in alphabetical order, the emu (*Dromaius novaehollandiae*) from Australia (see Figure 23.1), the kiwi (from New Zealand), the ostrich *(Struthio camelus)* from Africa (see Figure 23.2), and the rhea (e.g., the greater rhea—*Rhea americana*) from South America (see Figure 23.3). These birds all have powerful legs and leg muscles but small wings and breast muscles. Moreover, they have long necks for foraging for plants. The ratites are often thought to be primitive birds. For instance, the feathers are primitive and are not interlocking as with other birds.

Evolution and Classification

Although ratites look very similar, they evolved from different groups of birds that could fly. Given the evolutionary separation of the ratites, caution is expressed about extrapolating from conclusions in one ratite species to another and particularly from chickens to ratites. The classification of ratites is as follows:

Phylum: *Chordata*
Subphylum: *Vertebrata*
Class: *Aves*
Subclass or infraclass: *Palaeognathae* (as opposed to the *Neognathae* containing all the familiar species of birds)

1. Ostrich
   Order: *Struthionidae*
   Species: *Struthio camelus*
2. Emu
   Order: *Casuariiformes*
   Species: *Dromaius novaehollandiae*

Figure 23.1 Emu hen (*Dromaius novaehollandiae*) with 16 chicks in Australia. (Source: John Carnemolla/Shutterstock)

3. American Rhea
   Order: *Rheiformes*
   Species: *Rhea americana*
4. Darwin's rhea
   Order: *Rheiformes*
   Species: *Rhea pennata*

Domestication

Ratites have been domesticated in the past 150 years. Ostriches and emus are produced commercially, with the major producers being Southern Africa and Australia, respectively. There has been a significant growth of emu and ostrich production in both the United States and countries in the European Union. In the United States, the ratite industry has approximately 1,000 ostrich growers raising about 100,000 birds; 10,000 emu growers with about a million birds; but only 15,000 rheas.

Until recently, the meat was essentially a by-product (see Figure 23.4), and ostriches were raised for hide for leather crafting (see Figure 23.5). Feathers

Figure 23.2 Ostrich (*Struthio camelus*). (Source: Aaron Amat/Shutterstock)

Figure 23.3 Greater rhea (*Rhea americana*). (Source: Karel Bartik/Shutterstock)

TEXTBOX 23A

A Deeper Dive: The Evolution of Ratites

Existing ratites include ostriches (Africa), emus (Australia), rheas (South America), and cassowaries (New Guinea). These are all classified in the subclass *Palaeognathae* (class *Aves*) along with the flightless kiwi (New Zealand) and flighted tinamous (South America). It has been widely held that the existing ratites together with recently extinct large flightless birds (moas of New Zealand and elephant birds—genera *Aepyornis* and *Mullerornis*—of Madagascar) represent a group of flightless birds that then diverged after the breakup of the supercontinent Gondwana, or Gondwanaland, in the Cretaceous period (Cracraft, 1973). Comparative genomics does not fully support this. To quote H. L. Mencken, "There is always a well-known solution to every human problem—neat, plausible, and wrong."

Instead, the sister taxa are moas and tinamous; elephant birds and kiwis; emus and cassowaries; with ostriches alone (Cooper et al., 1992; Mitchell et al., 2014). The available evidence favors the proposition that both flightlessness and gigantism evolved at least four times from flighted ancestors, filling the herbivorous niches left open by the demise of the dinosaurs (Harshman et al., 2008; Mitchell et al., 2014).

(from ostriches) (see Figure 23.6) and oil (from emus) are other important by-products. Emu oil is used, for instance, in cosmetics. Advantages of emus and ostriches are the quality of the hide, the feathers, the meat, and the rapid growth rate. The composition of ostrich and emu meat is shown in Table 23.1.

With the possible exception of sales of founder breeding stock, profitability in the last 15 years in the ratite industry has been low. Costs for raising emus and ostriches are relatively high. These include bird housing and land, feed, incubation facilities for eggs, and veterinary care.

Common Issues with Ratites

Animal Health

There should be programs to protect young ratites from predators and to control infectious diseases and parasites. Vaccinations of ostriches are available for Newcastle disease, avian influenza, and *Clostridium perfringens*. The proventriculus (stomach) of ratites can

Figure 23.4 Ostrich steak served as a salad. (Source: Wiktory/Shutterstock)

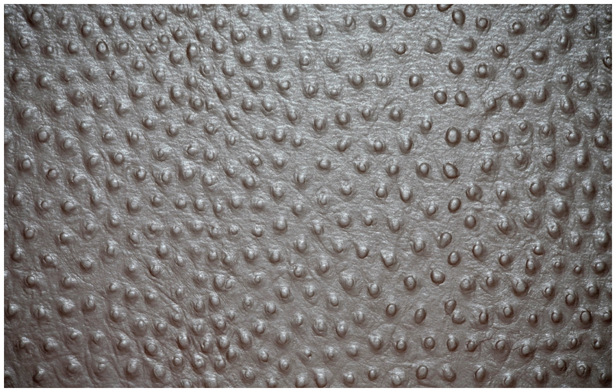

Figure 23.5 Ostrich leather. (Source: Iurii Davydov/Shutterstock)

Figure 23.6 An ostrich feather. (Source: Anton Starikov/Shutterstock)

Table 23.1 Comparison of the composition of meat of ratite, pigeon, game birds, and chicken.

	Energy (kcal per 100 g)	Protein (g per 100 g)	Lipid (g per 100 g)	Calcium (mg per 100 g)
Chicken (Ground)	143	17	8	6
Ostrich (Ground)	165	20	9	7
Emu (Ground)	134	12	4	7
Pigeon (Squab Meat and Skin)	294	18	24	12
Guinea Hen (Meat and Skin)	158	23	6	11
Quail (Meat and Skin)	192	20	12	13
Pheasant (Meat and Skin)	181	23	9	12

become impacted. Care should be taken to exclude materials that may become impacted, including straw, litter, long grass, sticks, leaves, sand, and stones.

Biosecurity

Biosecurity is critically important to ostrich and other ratites. It is advisable that there should not be other livestock or poultry on the same farms or animal facilities.

Safe Handling of Ratites

The risks from handling ratites are injuries to the birds and potentially to the people. They can be restrained by a "V" shaped crush arrangement.

Transportation

Ostriches and other ratites have a high center of gravity (heavy body and long thin legs) and feet with only two toes on each. Transportation of ratites is more difficult because the birds have trouble maintaining their balance, compromising their welfare. They should be transported in single-decked livestock trailers with a density of 0.5 m^2 per bird.

Euthanasia / Slaughter

Ratites are electrically stunned so they are unconscious before they are killed by bleeding.

Ratite Production and the Environment

There is marked production of methane in ostriches and also in both emus and rhea. This might be expected for herbivores but not based on the anatomy and physiology of the gastrointestinal tract.

Gastrointestinal Functioning

Emus (*Dromaius novaehollandiae*) have much smaller colons and ceca compared to ostriches, with rhea intermediate. Moreover, there are marked differences in retention time for small fiber particles (2 mm) in the gastrointestinal tract (ostrich: 30–36 hours; greater rhea: 7–19 hours; emu: 1.3–1.8 hours).

23.3 Ostriches

Ostriches are the world's largest birds and were once known as the camel-bird. Adult ostriches are about 7 1/2 ft. high (~2.75 meters), weigh about 300 lb (140 kg), and can live to be 70 years old (see Figure 23.2). The ostrich cannot fly, but it can run fast, attaining a speed of up to 40 miles (~65 kilometers) per hour. This helps explain why ostrich racing is a popular sport in some parts of the world.

Ostriches probably evolved in Africa but extended their range over geological history to include Eurasia. Wild ostriches are found in much of Africa, and until about 100 years ago also in Arabia and the Middle East. Based on the latter, it is not surprising that ostriches are mentioned in the Bible (e.g., Job 39:13–18 and Isaiah 34:13).

Subspecies

There are four subspecies of the single ostrich species, which are limited to distinct geographical regions in Africa (see Figure 23.7):

- *Struthio camelus camelus* (North Africa)
- *Struthio camelus molybdophanes* (Africa/Horn of Africa)
- *Struthio camelus massaicus* (East Africa—Kenya and Tanzania)
- *Struthio camelus australis* (South Africa)

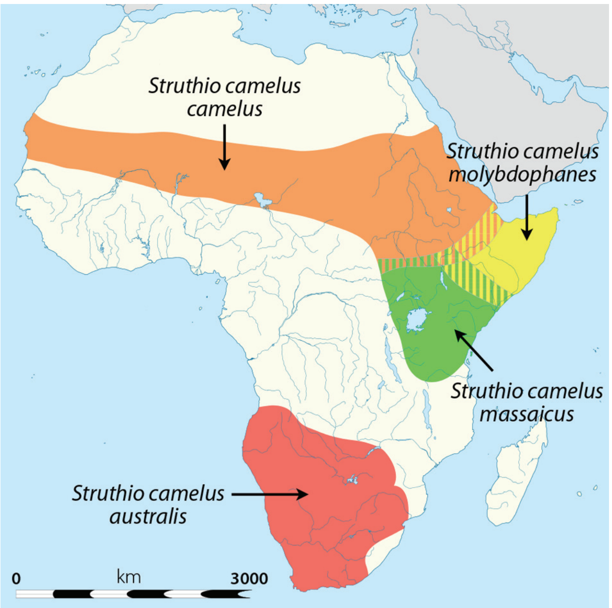

Figure 23.7 Distribution of ostrich subspecies in Africa. (Source: Wikimedia Commons)

History of Ostrich Farming/Ranching

Ostriches were domesticated in Algiers (North Africa) in 1857 and South Africa in 1865. Farming was initiated to enhance production of feathers, which were used extensively in fashionable hats, and so on. There was a peak in farmed ostriches in 1914 with about 800,000. With the onset of World War I, demand for feathers plummeted, as did ostrich numbers. The farmed ostrich (sometimes referred to as *S.c. domesticus*, or the black) is predominantly derived from chicks from wild populations of *S.c. massaicus* (red-necks) and *S.c. australis* (blue-necks).

Size of Ostrich Production in the World

The cumulative total of ostriches slaughtered in the world is 371,000 per year, resulting in about 80 million pounds (35 thousand metric tons) of meat. The top producer is South Africa, with the country's ostrich production being about 150,000 birds slaughtered per year in 2012 (down from 340,000 produced in 2002). Sales of South African ostrich products include meat (45%), hides (45%), and feathers (10%).

Production also occurs in South America (100,000 birds in 2012 compared to 14,000 in 2002), the United States, the Middle East, Europe, and Australia.

Biology of Ostriches

Gastrointestinal Physiology /Anatomy and Nutrition

Ostriches are herbivorous and grazers. The ostrich gastrointestinal tract resembles on a larger scale that of the chicken but without a crop. Ostriches swallow stones to aid gizzard grinding of feed. Moreover, about 2% of feed consumed is soil. This can affect mineral nutrition either as a source of minerals or by chelation (decreasing absorption of specific minerals). To utilize plant hemicellulose and cellulose, ostriches are post-gastric or hindgut (ceca and colon) fermenters and have a slow gastric passage rate of about 48 hours. In the adult ostrich, the ceca are 90 cm (3 ft) long and the colon is 16 meters (52.5 ft) long. Because of this, metabolizable energy (ME) values underestimate the true ME contents of feed ingredients. Similarly, digestibilities of individual amino acids are consistently higher than in chickens.

Water Balance

As the name camel-bird might imply, the ostrich has relatively low water needs. Studies indicate that when water is available, an ostrich will gain water from drinking (7.9 liters/day), metabolism (0.4 liters/day), and food (0.2 liters/day), and lose water in feces and urine (5.4 liters/day) and by evaporation (for cooling) (3.1 liters/day).

Activity

Unlike other poultry and livestock that are relatively inactive, ostriches are active for about 43% of the day, being engaged in walking, running, and fighting.

Hormones

Ostriches and emus have the full repertoire of avian hormones. However, ratites appear to have abnormal thyroid function, resulting in their neotenic or "infantile" appearance.

Growth

Growth rates in young ostriches (see Figure 23.8 for example of young ostrich) vary considerably. On average, female ostriches grow faster than males, gaining 1.6 kg (3.5 lb) per week compared to 1.2 kg (2.6 lb) per week in males. Average growth rates of 1 lb/day (0.44 kg/day) have been reported in ostriches (at 100–150 lb or 50–70 kg).

Reproduction

Both wild and farmed ostriches are seasonal breeders. The breeding season varies with the country and geography where the ostriches are raised. For instance, in South Africa, the breeding season is be-

Figure 23.8 A farmed ostrich chick. (Source: Thomas Pries/Wikimedia Commons)

tween June and February (midwinter through late summer). In Australia, it is between July and March (midwinter through late summer). In contrast, the breeding season in the United States is May to September (late spring to the end of summer). However, close to the equator, ostriches may breed throughout the year.

The anatomy and physiology of the reproductive system of the ostrich is essentially very similar to that in the chicken (see Chapter 4), except in scale. For instance, each teste of the adult male is 6 in. (15 cm) long and 8 in. (20 cm) in circumference. In the wild, and with many farmed ostriches, a female (or hen) ostrich will incubate about 20 eggs at a time when with other females. The "major" or "dominant" female incubates the eggs frequently, discarding eggs that are not her own.

Practical Aspects of Reproduction

Adult breeding ostriches are farmed either in pairs (one male and one female) or trios (one male and two females). The only reliable method of determining the sex of young chicks is examining the sex organs. It is advisable to keep the males and females separated prior to pairing for mating. Pairs of ostriches are maintained in breeder camps or paddocks. Breeding paddocks 0.25 or 0.5 hectares in size have been used successfully with either little or no pasture and fenced with smooth wire about 6 ft high (~2 m).

Farmed ostriches show much lower reproductive efficiency and fertility than chickens. In a single breeding season, a mature female ostrich will lay about 50 eggs (compared to more than 300 per year in a chicken) (see Figure 23.9). However, about half of the adult hens do not produce any eggs. Nutrition is critical to reproduction, but requirements are still not adequately documented.

Infertility

Female infertility includes vaginal prolapse, egg retention, and oviductal infections. Male infertility may be age related (male too young) or due to exhaustion of spermatozoa supplies due to repeated mating during prolonged egg-laying in females.

Artificial Insemination

Artificial insemination is beginning to be employed. Ostrich semen can be collected manually into a warmed collection tube. Injections of oxytocin have been found to increase semen volume.

Characteristics of Ostrich Eggs

Ostrich eggs have a similar composition to chicken eggs but obviously differ in size (see Figure 23.9). Indices of ostrich eggs are summarized in Table 23.2. What is surprising is that despite the size of the egg, the incubation time is as low as 42.8 days. Comparisons of incubation in different species are summarized in Table 23.3.

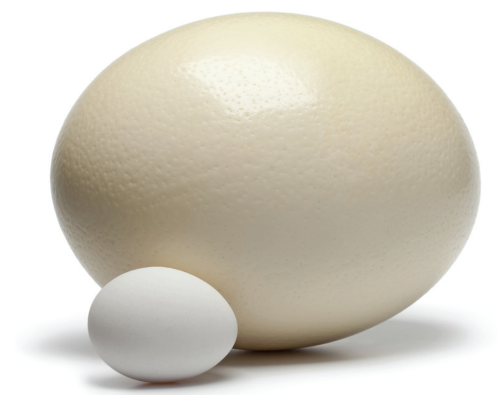

Figure 23.9 An ostrich egg and chicken egg. (Source: picturepartners/Shutterstock)

Table 23.2 Indices of incubation and early post-hatch life in ostriches.

Parameter	Mean Value in Ostriches
Egg weight (kg)	1.5 (1.0–2.0)
Egg fertility (%)	50–85
Duration of incubation (days)	42.8
Weight of 1-day-old chick (kg)	0.8
Bacterial contamination of eggs (%)	13
Mortality of chicks in first 28 days (%)	47

Egg Storage and Incubation

As opposed to the placing of eggs in nests by many other species of birds, ostriches bury their eggs. Thus, the techniques of egg storage and incubation by the industry must mimic the natural conditions. It is critically important to store ostrich eggs under conditions optimal for viability during incubation, hatching, and post-hatching growth. Eggs should be collected within 1 day of laying and stored at ~63°F (~17°C) and relative humidity (RH) of 35–75% after disinfection. With prolonged storage, there are decreases in the number of chicks hatching. Incubation temperature is thought to be optimal at 97.5°F (36.4°C). Eggs should be positioned with the large end up at a 45-degree angle and be turned twice daily.

Table 23.3 Relative sizes and incubation conditions of exotic domestic birds.

Parameter	Ostrich (*Struthio camelus*)	Emu (*Dromaius novaehollandiae*)	Japanese Quail (*Coturnix japonica*)
Body weight	140 kg	39 kg	125 g
Egg weight	1.5 kg	550 g	10 g
Duration of incubation (d)	42.8	54–57	17
Incubation temperature (°C)	36–36.5	34.9–36.3	37.5
Newly hatched chick weight (g)	800	450	6.5

Source: Brake and Rosseland, 1995; Randall and Bolla, 2008.

TEXTBOX 23B

A Deeper Dive: Egg Incubation and Early Post-Hatch Development of Ostriches

Incubation

The following are indices of incubation in ostriches:

- Hatchability of ostrich eggs: 37–52%
- Incubation temperature: 36.0–36.5°C at 24% or 30% relative humidity (RH) (Hassan et al., 2004; İpek and Şahan, 2004; Brand et al., 2015a; Deeming, 1997; Cooper, 2001).
- Egg turning is reported as the following:
  - — Eggs turned every hour through a 60° or 90° angle (Brand et al., 2015a).
  - — Eggs turned every hour through a 45° angle (İpek and Şahan, 2004).
- Possible forced draught incubators: Buckeye, Pro-hatch, Natureform, or African International incubators (Brand et al., 2015).
- Incubator ventilation is important to remove carbon dioxide and water vapor with 48 m^3 h^{-1} 1000 $eggs^{-1}$ recommended (Deeming and Ar, 1999).

Time in incubator:

- Option 1: 35 days, then the eggs are moved to a hatcher also at 96.8°F (36°C) and at 24% RH (Brand et al., 2015).
- Option 2: 39 days, then eggs transfer to a hatcher at 96.8°F (36°C) and 40% RH until hatching (İpek and Şahan, 2004; Brand et al., 2015a).

Mortality of chicks:

- 47% in the first 28 days
- 31% between 28–90 days (Cloete et al., 2001).

Post-Hatching Management

Chicks are allowed to dry off in the hatcher for up to 24 hours and then can be transferred to an intensive chick-rearing facility (Cloete et al., 2001). Chicks are initially raised at 86–89.6°F (30–32°C) at a density of six chicks per m^2, usually with access to the outdoors. The density is decreased by 10% per week and temperature is gradually reduced to 78.8°F (26°C) at 3 weeks old (Verwoerd et al., 1999).

Brooding and Rearing

The brooding period of young ostriches (chicks) is very critical. Chicks should be brooded at a temperature of about 90°F (32.2°C) for 14 days. Following this, the temperature is reduced a few degrees each week.

Ostrich Production on Pasture

Ostriches are raised on pasture with shelter provided. If the stocking density is between 0.1–1.0 birds hectare^{-1} (0.04–0.4 birds acre^{-1}) on pasture, there can damage to the pasture. Some pastures are thought not suitable for ostriches (e.g., Bermuda grass). On the other hand, lucerne (*Medicago sativa*) pastures are highly suitable for raising ostrich. Ostrich pens need to be fenced, with 9-gauge chain-linked fencing being preferred. Areas with ratites should be surrounded by closely woven wire fences 1.8–2.4 m high (6 to 8 feet) high.

Limitations to Ostrich Production

The efficiency of production is low for a number of reasons. There is a lack of knowledge of optimal nutrition, disease prevention, and environmental conditions (e.g., ventilation). Genetically improved emus and ostriches have not been developed due to the forming of breeding pairs. Until recently, artificial insemination had not been developed. This slowed development of selective breeding programs (to improve growth rate, disease resistance, etc.) Moreover, there are technical problems as indicated by the low hatchability of eggs and relatively high post-hatch mortality.

With commercial ratite production around the world, the birds are being exposed to diseases that they have not previously seen. Mortalities of over 25% have been reported in the first 3 months of life for ostriches. Skewed sex ratios (more males) are due to higher mortality and incubation failures in females.

At this time, there has been little consolidation or vertical integration with concomitant economies of scale. In summary, the major biological limitations to ostrich farming are low egg fertility, low hatchability, and relatively high chick mortality

TEXTBOX 23C

A Deeper Dive: Ostrich Nutrition

Ostriches require 230 g of protein/day, 14.8 g of lysine/day, and 16.5 g of sulphur amino acids/day (du Preez, 1991). Breeding pairs can be fed three times a week with 5 kg of dry matter per pair per day (9.2 MJ ME per kg) with water available ad libitum (Brand et al., 2015a). No differences are observed in eggs or chicks produced with diets containing between 75 and 140 g crude protein per kg (or between 2.9 and 5.8 g of lysine per kg or between 2.1 and 4.3 g of methionine and cysteine per kg) (Brand et al., 2015a).

Feed ingredients can include alfalfa meal, oat bran, maize, wheat bran, and lucerne hay, with protein from soybean oil cake and sunflower oil cake (Brand et al., 2015a; b). During the breeding season, reproduction is successful with 2 kg/bird/day of a ration containing (180 g CP, 10 MJ) supplemented with fresh alfalfa (İpek and Şahan, 2004). Diets are supplemented with limestone (3.5%) and calcium phosphate (2.1%) to supply the calcium needs of producing the egg shells, and can be pelleted. A vitamin and micromineral pre-mix is required to be added to the diet for optimal egg production and hatchability. Diets for adults outside the breeding season can be 1·5 kg/bird/day of pelleted, dried alfalfa.

Safe Handling of Ostriches

Ostriches can be restrained by a "V" shaped crush arrangement. It can be useful to hood the ostrich's head to calm the bird. Use a shepherd's crook when placing a hood on the ostrich's head.

Slaughter

In many countries—such as the United States, Australia, and Europe—ostriches go to market at 9 months of age (190 lb or ~85–90 kg). This optimizes the economics of ostrich meat production with feed: gain declining after this age. In South Africa, ostriches are slaughtered at 14 months because this results in the best hides for leather. Feathers are harvested on the farm. Ostriches are transported to abattoirs for processing plants. Birds are slaughtered by electrical stunning or captive bolt. Following bleeding out, the plucking is completed and the head and hide are removed. This is followed by evisceration and, finally, removal of meat cuts.

Characteristics of Ostrich Muscle/Meat

The composition of ground ostrich meat according to the USDA's National Nutrient Database is shown in Table 23.1. Ostrich ground meat is low in fat (2.4% or 2.4 g per 100 g) and high in protein (22%), water (76%), and low energy (126 kcal per 100 g). The low fat content is due to there being little intramuscular fat. The fatty acid profile differs from most meats being 37% saturated fatty acids, 32% monounsaturated fatty acids, and 32% polyunsaturated fatty acids.

Ostrich meat is less juicy than beef or chicken due, in part, to the low fat. This problem is accentuated if the meat is overcooked (it should not be cooked "well done"). Ostrich meat can be used in most processed meats, particularly as a replacement for beef. The high pH value indicates that it should not be used for raw hams.

23.4 Emus

There is even less information about emu production than there is for ostriches. In general, emu husbandry is assumed to be similar to that of ostriches.

Nutrition

Emus can be raised on pasture with a night shelter and, in addition to forages, they should receive supplements of barley, alfalfa, and canola. The calcium requirement is increased to over 2% when laying eggs.

Slaughter

Slaughter of emus can employ electrical stunning prior to slaughter or a modified captive bolt.

Meat

The composition of emu ground meat is shown in Table 23.1. It has even lower fat content than ostrich meat.

Reproduction

Reproduction is seasonal in emus. Like sheep, they are considered short-day breeders (requiring short daily photoperiods to come into reproductively mature/active condition). As emus form pair bonds, genetic improvement is difficult. With the development of artificial insemination, it will be possible to use superior males for genetic improvement. Breeding pairs of emu are held in a fenced pen at least 8 m wide × 20 m long.

Incubation

Incubation involves emu storage at 28–33% RH and incubation at 34.9–36.3°C for 54–57 days (see Table 23.3).

23.5 Pigeons

Pigeons (see Figure 23.10) are used for meat production. Pigeon consumption was high in Europe in wartime and in North America during the Great Depression. Pigeons can be raised by pigeon fanciers (hobbyist breeding for flyers, performers, and fancy pigeons for showing) or by pigeon racers. Pigeon racing has a relatively low number of enthusiasts. Using statistics from the Chinese Racing Pigeon Association, only 45% return home in races. It is not clear whether the non-returners died, were killed by predators or other people, or returned to the wild. Without this information, the ethics of this activity is open to question.

Classification

Pigeons are classified as follows:

Phylum: *Chordata*
Subphylum: *Vertebrata*
Class: *Aves*
Infraclass: *Neognathae*
Superorder: *Neoaves*
Order: *Columbiformes*
Species: *Columba livia* (pigeon, rock dove, or rock pigeon); domestic pigeons have been referred to in the past as *Columba domesticus*.

Figure 23.10 A pigeon (*Columba livia*). (Source: Neungdesign/Shutterstock)

Domestication

Pigeons were probably domesticated about 5,000 years ago. Paintings and carvings showing these birds have been found in the ancient cultures of Europe, Asia, and the Near East. Pigeons and doves have been traditionally associated with peace and love.

Pigeon Meat

Pigeon meat is sold as either squab (young, immature pigeon) or pigeon (adult male or female). Squab is less than 4 weeks old and is exceptionally tender meat, while pigeon is a tougher meat. Squab has a high fat content. An uncooked, dressed squab is about 57% water, 24% fat, and 19% protein (see Table 23.1). For an example of an Asian pigeon dish see Figure 23.11.

Figure 23.11 Fried pigeon with pakchoi vegetables is an Asian dish. (Source: Rapaeh/Shutterstock)

Breeds

Through the centuries, selective breeding of pigeons has resulted in about 200 different breeds, each with a distinct behavior, size, shape, stance, feather form, and colors. The Homer, White King, and Swiss Mondaines are the most popular.

Breeding

Pigeons are ready to mate at about 4 to 5 months of age. They mate in pairs and usually remain with their mates throughout life. The pigeon hen lays an egg, generally skips a day, then lays again. The incubation period is about 17 days. Both males and females sit on or incubate eggs. Both parents care for the young, called squabs (the newly hatched chicks are sometimes referred to as squeakers). They feed them by regurgitating a thick, creamy mixture called pigeon milk into the open mouths of the young. This milk is produced by the crop when stimulated by the hormone prolactin. The "milk" consists of fat and protein from crop epithelial cells that are sloughed off. Pigeons grow rapidly. Squabs exceed the normal adult weight at the time they are ready to leave the nest at about 30 days of age.

Feeding and Watering

Pigeons are grain eaters. They prefer a variety or mixture of grains or commercial pigeon pellets.

23.6 Overview of Game and Ornamental Birds

Most game and ornamental birds are of the order *Galliformes*. Game birds are raised for sale to game preserves, shooting preserves, or for meat. Some producers raise them for profit, on a full-time or part-time basis. They also may be raised for pleasure. There is a market for the sale of ornamental birds. Unless otherwise stated, these game and ornamental birds should receive a commercial game bird diet (see Chapter 9 for details). If this is not available, turkey feed can be used. Water should always be available. These birds are subject to many poultry diseases and respond to the same treatments as chickens and turkeys.

23.7 Guinea Fowl

Domesticated guinea fowl are derived from helmeted guinea fowl (*Numida meleagris*) (see Figure 23.12). Jared Diamond (author of *Guns, Germs, and Steel*) considers that guinea fowl the only species of animal that was definitively domesticated in Africa, most probably West Africa. The name of guinea fowls derives from Guinea, a specific area on the coast of West Africa. They are produced in Africa and developed countries, including the United States.

There is a strong interest in increasing guinea fowl raising in Sub-Saharan Africa with support of the World Bank. The productivity of raising guinea fowl has been markedly improved by use of incubators and housing to protect them from hawks and other predators. Predators to guinea fowl include snakes, dogs, wild cats, and hawks.

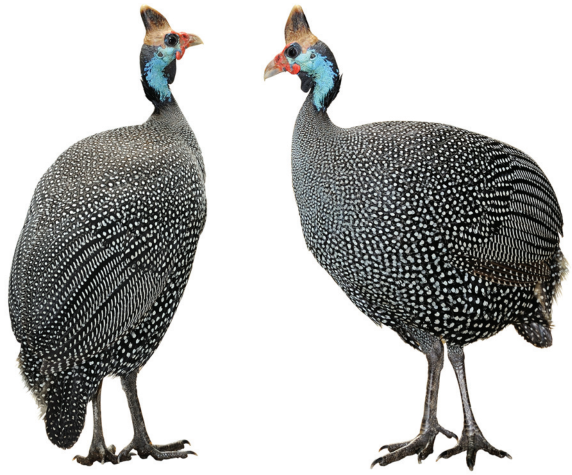

Figure 23.12 Guinea fowl (*Numida meleagris*). (Source: tristan tan/Shutterstock)

Figure 23.13 Baked guinea fowl can be an enjoyable meal. (Source: Maria Kovaleva/Shutterstock)

Definitions

Guinea fowl are also called "pintades" or "gleanies."
Female guinea fowl are guinea hens or guinea fowl hens.
Male guinea fowl are guinea cock or guinea fowl cock.
Young guinea fowl are called keets.
Guinea fowl meat is referred to in the US as guinea hen(s). It is also called guineas.

Classification

Guinea fowl are classified as follows:

Phylum: *Chordata*
Subphylum: *Vertebra*
Class: *Aves*
Order: *Galliformes*
Infraclass: *Neognathae*
Superorder: *Galloanserae*
Family: *Numididae*
Species: *Numida meleagris*

Guinea Fowl Meat

The meat of guinea fowl is tender and flavored like wild game. The composition of guinea hen is shown in Table 23.1. Guinea fowl meat is low in fat and high in protein. Guinea hens (guinea fowl) are served at some restaurants or at banquets as a special delicacy (see Figure 23.13). Guinea fowl are also both popular and profitable in Africa. Moreover, production of guinea fowl can alleviate poverty and protein deficiency.

Varieties

The three principal varieties of domesticated guinea fowl in the US and elsewhere are Pearl, White, and Lavender.

Reproduction

Guinea fowl are season breeders with reproduction brought on by long daylights. Hens can lay more than 100 eggs per year. It is recommended that eggs be collected four times each day and then placed into a storage facility. With extreme weather conditions, such as high temperatures, the number of times eggs are picked up each day needs to be increased. The incubation period is 26 to 28 days. Incubators should be maintained at a temperature of between 99–99.5°F (37.2–37.5°C) and a humidity of 57 to 58%. The eggs should be turned three times per day. There are reports of successful matings between guinea fowl and chickens resulting in guinea × chicken hybrids (or guin-hens).

Rearing

The three methods of rearing guinea fowls are (1) free range, (2) semi-free range, and (3) intensive. Under free-range and semi-free range conditions, guinea fowl roost in trees. A major issue is the loss of eggs to predators and high death rate of the keets. It is recommended that free-range or semi-free range guinea fowl should not be raised close to residential areas or neighbors as their vocalizations are very loud. Intensive production is done with low light intensity to reduce "flightiness." Guinea fowl are marketed at 12–15 weeks old with a live weight of 2 3/4 to 3 1/4 lb (1.25 to 1.47 kg) and a dressed weight of 2 1/4 to 2 3/4 lb (1.02 to 1.25 kg).

Feeding and Watering

Under intensive conditions guinea fowl are fed diets that are high in protein (see Table 23.4). In free-range or semi-free-range small-scale production, the guinea fowl eat plants, insects, and other arthropods, as they are excellent foragers. This has the advantage of reducing pest insects and vectors for human and livestock diseases. They are also less vulnerable to mycotoxins (fungal toxins). They can be supplemented with a commercial turkey breeder mash (22–24% protein) that can be fed to layers. Young guineas can have a growing turkey diet.

Diseases

Guinea fowl are relatively resistant to many infectious diseases of chickens. However, it is advantageous to vaccinate against Newcastle disease. Guinea fowl are impacted with increased morbidity and mortality by parasites. The parasites and parasitic diseases including: coccidiosis, trichomoniasis, roundworms, and fleas or lice. Keets are particularly vulnerable to mites. The parasites can be controlled by coccidiostat, antihelmintics, and insecticides leading to greatly improved performance.

23.8 Other Game and Ornamental Birds

Partridge

Both the gray partridge or Hungarian or English partridge (*Perdix perdix*) of Europe and the Chukar of Asia (*Alectoris chukar*) (see Figure 23.14) have been introduced into the United States. Hungarian partridges, sometimes referred to as gray cannonballs, were introduced into the Western United States early in the twentieth century. Today, most partridges are found on the Canadian plains and in the North Central and Northwestern United States. Figure 23.15 illustrates roast partridge.

Figure 23.14 Chukar partridge (*Alectoris chukar*). (Source: kavcicm/Shutterstock)

Figure 23.15 Two roast partridges. They are served covered with bacon and surrounded by roast carrots. (Source: DronG/Shutterstock)

Table 23.4 Dietary requirements for guinea fowl.

	Metabolizable Energy (MJ/kg)	Protein (%)	Calcium (%)	Available Phosphorus (%)
Starter	12.13	24–25	1.2	0.5
Grower 1	12.13	20	1.0	0.5
Grower 2	11.30	15	0.8	0.4
Breeder	12.13	18	3.0	0.4

Coturnix Quail

Coturnix quail are divided into two species, the European quail (*Coturnix coturnix*) and the Japanese quail (*Coturnix japonica*) (see Figure 23.16). The European quail is also known as coturnix quail, pharaoh's quail, stubble quail, and eastern quail. The Japanese quail is smaller than the Bobwhite quail, but it produces a larger egg. Japanese quail were either domesticated in Japan about the eleventh century or brought to Japan from China about that time. They were first raised

Figure 23.16 Japanese quail (*Coturnix japonica*) are used for production of meat and eggs together with as laboratory animals. (Source: Eric Isselee/Shutterstock)

Figure 23.17 Quail eggs are used in some gourmet foods. (Source: K. Suzuki/Wikimedia Commons)

as pets and singing birds. By 1900, these quail had become widely used for meat and egg production in Japan. Japanese quail were imported into the United States from Japan. Japanese quail are used for eggs, meat, training hunting dogs, and research (they are a useful model for poultry).

Meat

Quail are the key ingredient in various dishes. The composition of quail meat is shown in Table 23.1.

Eggs

Quail eggs (Figure 23.17) are considered as delicacies in many places including Japan in sushi, Republic of Korea as hardboiled, Indonesia as satay, and in up-scale French and bistro-style restaurants. The composition of quail eggs is shown in Table 23.5. They are similar in composition to chicken eggs.

Breeds

The following varieties (breeds) of Japanese quail are known: Manchurian Golden, British Range, English White, and Tuxedo.

Bobwhite Quail (*Colinus virginianus*)

The name Bobwhite comes from its call. In the spring, cocks that are not yet paired sound their loud, tuneful "bobwhite" call. The Bobwhite quail (see Figure 23.18) lives on fallow fields, meadowlands rich in bushes, and open woodlands from the Canadian border to Mexico and Cuba. Bobwhite quail are raised on quail farms mainly for hunting purposes and as a test species for toxicology of pesticides, etc.

Pheasants

Pheasants are generally classed as game birds (see Figure 23.19). Pheasants originated in Eurasia. They were first brought to North America by Benjamin Franklin's son-in-law, but the venture was unsuccessful. Later, the US Consul in Shanghai sent 28 Chinese pheasants to Oregon. This latter introduction met with success.

Meat

Pheasants are cooked in a variety of dishes. The composition of pheasant meat is shown in Table 23.1.

Table 23.5 Comparison of the composition of eggs from quail and chickens.

	Energy (kcal per 100 g)	Protein (g per 100 g)	Lipid (g per 100 g)	Calcium (mg per 100 g)
Chicken Egg	143	13	10	56
Quail Egg	158	13	11	64

Data from the USDA National Nutrient Database.

Figure 23.18 Bobwhite quail (*Colinus virginianus*). (Source: Bonnie Taylor Barry/Shutterstock)

Figure 23.19 Ring-necked pheasant (*Phasianus colchicus*). (Source: Piotr Krzeslak/Shutterstock)

Breeds

Pheasants are classed as (1) game breeds or (2) ornamental breeds. The game breeds are Blackneck pheasant, Chinese Ring-necked pheasant, English Ringneck pheasant, Formosan pheasant, and Melanistic Mutant Mongolian pheasant. The ornamental breeds are Lady Amherst's pheasant, Golden pheasant, and Reeves's pheasant. The Chinese Ring-necked pheasant is the most popular variety.

Peafowl

The peafowl belongs to the same family as pheasants and chickens, differing particularly in plumage. Peafowl, particularly peacocks, are kept as ornamental birds because of their tail displays (see Figure 23.20). The Blue peafowl (*Pavo cristatus*) (see Figure 23.20) is native to India and South Asia. About 300 BC, Alexander the Great introduced the birds to Greece.

Definitions

Peacock: An adult male peafowl.
Peahen: An adult female peafowl.

Species

The three species of peafowl are (1) Indian Blue or Indian peafowl or Blue peafowl (*Pavo cristatus*) (see Figures 23.20 and 23.21), (2) Java Green (*Pavo muticus*), (3) and Congo (*Afropavo congensis*). The Indian Blue is the most common.

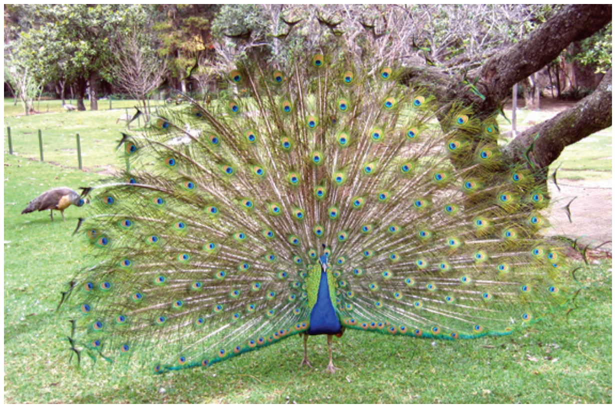

Figure 23.20 A peacock (*Pavo cristatus*) showing full sexual display in the breeding season. (Source: Alex Pronove/Wikimedia Commons)

Figure 23.21 The head of a peacock. (Source: PCHT/Shutterstock)

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Successful Application and Interviewing for a Position

24

SECTIONS

OBJECTIVES

After studying this chapter, you should be able to:

1. Understand the characteristics that employers want.
2. Understand the advantages of internships, extracurricular activities, graduate school, and professional school.
3. How to build a resume.
4. Know how to prepare for applying for a job or internship.
5. Know what goes into a resume (or curriculum vitae) and how to write one.
6. Know what goes into a cover letter and how to write one.
7. Know how to seek information about the position.
8. Know what it takes to be a "winning" candidate at an interview.
9. Understand the types of questions that might be asked at the interview.
10. Know when to show up for an interview
11. Know the "dos and don'ts" of interviewing.
12. Know how to dress for an interview.
13. Understand what is expected at an interview meal.
14. Understand what the advantages of internships are.

24.1 INTRODUCTION

While studying poultry science and animal science is usually fun, a major reason for the programs is to prepare for a career. This chapter will help you prepare for the next steps. It is never too early to start getting ready for your career. Careers for poultry science graduates and others in the animal sciences include the following:

1. Agricultural business and finance (loan officer, equipment design, and sales).
2. Agricultural sales and marketing (salesperson).
3. Biotechnology.
4. Extension-4H, county agents, state specialist.
5. Food industry (marketing, sales, new food development).
6. Food safety.
7. International agriculture (US government or nongovernmental representation, international sales, and market development).
8. Meat science (USDA inspectors, plant supervisors, managers, etc.).
9. Nutrition and feed industry (feed-processing supervisors, managers, nutritional consultants).
10. Poultry breeding/genetics (unit supervisors, executives, managers, etc.).
11. Poultry health (sales, research, management).
12. Poultry companies (technical representative, manager).

13. Poultry production (unit supervisors, executives, managers, etc.), quality control, information analyst, human resources.
14. Poultry promotion and information (article writer, marketer).
15. Research (laboratory technician, researcher, following MS or PhD for industry, government, and universities).
16. Teaching/education (instructor of vocational agriculture in high schools, professor at community or technical college or 4-year college or research universities).
17. Veterinary medicine (following DVM, many opportunities).
18. Welfare assurance.

It is critically important to start building the skills and experiences necessary to make you a winning candidate. This goes much beyond your class work. Good grades are useful but not sufficient for success. It is suggested you develop a network of colleagues (in your program and other universities) and in your chosen industry (see Figure 24.1).

Other ways to develop or strengthen your resume are the following:

Figure 24.1 Developing a social network and professionalism can be very important to your career. (Source: Luba V Nel/Shutterstock)

- Leadership in student organizations that increase problem-solving skills and the ability to work with others in team.
- Internships.
- Research or international experiences.

24.2 Resume Building and Networking

College is a time when you can hone your skills and develop in ways that you may not have considered. This could include the following:

- Taking a leadership role in student organizations.
- Seeing a different culture during an international experience.
- Doing an internship.
- Having research experience.

Textbox 24A

Matching You with the Right Opportunities/What Employers Want

When considering any career and your time as an undergraduate student, it is important to understand what employers want. Skills required include the following:

- Ability to work with other people in teams.
- Ability to lead.
- Problem solving ability.
- Ability to plan methodically.
- Ability to motivate others.
- Ability to think critically.
- Ability to work with numbers.
- Ability to write.
- Understanding of science.
- Ability to communicate successfully (orally and written).
- Creativity.
- Entrepreneurial.
- Ability to bring a task to completion.

The skills/abilities can be divided into basic skills:

- Skills directly affected by your college education such as oral and written communications together with analysis of data.
- The soft or people skills such as working in teams (these can be improved in extracurricular activities at college or internships).

Not only are new skills learned, but once you have a series of accomplishments under your belt, your confidence increases and you have something interesting to add to your resume. In addition, they give you something to talk about during an interview.

Networking

It is really important to develop your own network of people you can speak to and gain advice or information from. In turn, they can call upon you for advice or information as well.

Textbox 24B

Starting a Career

Advice for Finding a Job

- Start looking early.
- Network. (Note: Partying is not networking.)
- Do an internship.
- Be actively involved in career-related extracurricular activities.
- Be professional.
- Go to the university or college career center.
- Keep track of relevant activities and achievements.
- Develop relevant and superior skills such as written and verbal communication, problem solving, and working in teams.

Failing to do the above are among the top mistakes applicants make when looking for work.

Textbox 24C

Communication—Persuasive Speaking

Communication is based on what you say, how you say it, and how you look. There are estimates that 93% of all communication is nonverbal. Successful communication has the following components:

- Face, arms, and body (collectively body language) 55%
- Voice quality (e.g., intonation, pauses, accent) 38%
- The content—your words 7%

In order to be convincing, it is important that you project the following:

- Strength, not weakness.
- Confidence, not insecurity.
- Likability, not arrogance.
- Sincerity, not falseness.
- Look relaxed and steady, not tense or anxious or nervous, and speak with a strong voice.
- Speak clearly with authority, reasonably slow, and sufficiently loud so that people can hear you.

Good Body Language ("The Dos")

- Examples of good body language include your head held up with shoulders back, arms straight, leaning forward, standing erect and not stooped, and smiling and looking people in the eyes.

Bad Body Language ("The Don'ts")

Textbox 24C Figure 1 provides an example of bad body language. Examples of bad body language include crossing your arms; excessive blinking; biting your lip; covering your mouth; furrowing your brow; hands in a fist or in pockets; looking up as if wanting divine intervention; picking on face or nose; scratching anywhere (some places are worse than others); raised eyebrows; shifting multiple times while sitting; touching your nose, ear, or mouth; and twiddling thumbs or shuffling or tapping your feet.

Presentation

A good presentation should engender trust, consistency, and honesty; appeal to logic and emotion; and be clear, informative, and logical. Statistics can be very effective, particularly if coupled with a visual of some sort (e.g., a PowerPoint/multicolored pie chart).

Textbox 24C Figure 1 Body language is critically important in the interview situation. You need to appear to be trustworthy, professional, and likeable. If you look angry or aggressive (as in the image) you are unlikely to get the job. (Source: Kopytin Georgy/Shutterstock)

24.3 Resumes and Cover Letters

Preparing the Application

It is extremely unlikely you will get a job without applying for one, so get started early.

Your application should consist of the following:

- A resume customized for the specific job and individual employee.
- A cover letter explaining why you are well suited for the position and which of your skills are transferable to the employee.
- A list of references with addresses, telephone numbers, and email addresses.

It is strongly recommended that you do not rely entirely on "spell check" when preparing a resume, cover letter, and list of references. You may have the wrong word or even misspell a reference's name. If the application is to be submitted electronically, have everything prepared first. If you are sending your resume and cover letter electronically, send as PDF files.

Writing a Resume

It is important that your resume be easy to read, with each section clearly identified. Include sections such as education, skills, and relevant experience (see Figure 24.2).

Use a bold, large font and even break up the resume with shaded section titles. A resume should include the following:

- A resume should be specific for the job opportunity (read the job description).
- Use at least a 12-point font (e.g., Arial, Times, Times New Roman) with a larger font and bold for headings.
- Use bullet points.
- Use strong words such as *planned*, *managed*, and *innovated*.
- Name (with Mr. or Ms. if your gender is not clear from your first name).
- Contact information (e.g., address, telephone numbers, and email address).
- Objective (e.g., to obtain position [specifics] in *X* company or department).
- Education with graduation date and GPA.
- Employers/work experience with dates, responsibilities, and accomplishments, including relevant experience and including significant extracurricular activities, internships, and volunteer activities.
- Awards and honors (e.g., Dean's List, honor societies, competitive scholarships).
- Skills linked to the position you are applying for (e.g., foreign languages, computer programs, leadership skills).
- A list of references including their names, how they know you, and their contact information (addresses, email addresses, and telephone numbers).
- Proofread to check for errors. Ask someone you trust to review it.

Common Errors in Resumes

- Generic resume with cut and paste not well done.
- Not checking spelling. Use spell check (but know that it does not show if the wrong word is used) and grammar check.
- Font too small. Use 12 point as a minimum.
- No margin. A one-inch (2.5 cm) margin is recommended.
- An unprofessional or "cute" email address.
- Wrong length. It should be 1–3 pages.
- Use of weak verbs like *participate* or *support*. Use strong verbs such as *directed*, *managed*, *developed*, *planned*, *coordinated*, *organized*, *publicized*, and *marketed*.
- Any falsification, padding, or gaps.
- Abbreviations and acronyms. For instance, use Michigan State University, not MSU (the person reviewing your resume may be from Montana State University or Mississippi State University).
- Including information that is not directly relevant to the position. **Do not** include the following:
  - — Age.
  - — High school name if you have completed college.
  - — Hobbies (unless they are relevant to the position and you have accomplishments related to these).
  - — Marital status.
  - — Sexual orientation.
  - — Number of children.
  - — Pictures of yourself.
  - — Height and weight.
  - — Political affiliation (unless the position is political in nature, such as working as an intern in a congressional office).

Figure 24.2 *[Opposite page]* Example of a resume. While writing your resume, look at a number of templates and design yours so it is clear and assure that you standout. (Source: Viktorus/Shutterstock)

NAME SURNAME

PROFESSIONAL TITLE

LOCATION: CITY, STATE
PHONE: (012) 444-5555
E-MAIL: NAME@SERVER.COM

OBJECTIVE:

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Maecenas tortor dolor, pulvinar eget.

QUALIFICATION:

7 years experience as a aestibulum dignissim, sem sit amet aliquet varius
5 years experience of phasellus rhoncus diam et libero luctus egestas
4 years experience of fusce non tortor quam, ac viverra odio
7 years experience as a class aptent taciti sociosqu ad litora torquent per conubia nostra
3 years experience with etiam vitae interdum dolor

PROFESSIONAL EXPERIENCE:

CURRENT POSITION, CURRENT COMPANY — **2006 - PRESENT**

- Lorem ipsum dolor sit amet, consectetur adipiscing elit. Maecenas tortor dolor, pulvinar eget fermentum sed, convallis dignissim quam. Nulla eu est commodo leo porttitor consectetur. Aliquam vestibulum erat vitae arcu tristique quis ullamcorper lectus placerat.
- Vestibulum dignissim, sem sit amet aliquet varius, diam nulla malesuada arcu, aliquam lacinia arcu tortor quis ligula. Nulla fringilla metus ut lorem luctus ut iaculis erat tempor. Sed ornare fringilla nibh in aliquam. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Phasellus rhoncus diam et libero luctus egestas.
- Quisque tristique pharetra leo eget imperdiet. Mauris dictum tortor quis turpis luctus fringilla. Vivamus varius massa accumsan turpis bibendum dictum. Fusce non tortor quam, ac viverra odio.
- Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos himenaeos. Quisque et tempor sapien.
- Morbi ut euismod velit. Curabitur rutrum turpis a augue pharetra sodales. Etiam vitae interdum dolor.
- Mauris eros felis, gravida vitae euismod ut, ultricies eu turpis.
- Fusce non tortor quam, ac viverra odio.

PREVIOUS POSITION, PREVIOUS COMPANY — **2003 - 2006**

- Duis et justo odio, et eleifend augue. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia.
- Proin dictum, dui id adipiscing consectetur, tortor lacus pulvinar risus, vitae vestibulum justo mi ac justo.
- Nullam ac suscipit ipsum. Nulla suscipit nisi ligula. Nam in ligula eget erat tempor aliquet. In a pharetra metus. Aliquam tristique quam a est tempus fringilla. Sed consectetur libero sit amet magna pulvinar consequat.
- Aenean rutrum ante id arcu tincidunt id vehicula arcu imperdiet. Praesent sollicitudin nisi et nibh faucibus vitae sagittis quam porttitor. Quisque pellentesque, lectus in blandit varius, nisl erat venenatis dolor.

OLDER POSITION, PLACE OF WORK IN THE PAST — **2002 - 2003**

- Aenean suscipit neque at nisl mollis posuere. Suspendisse interdum tincidunt leo ac consequat.
- Quisque felis dui, sollicitudin in lobortis sed, molestie a diam. Vestibulum semper elit non dolor varius posuere. Cras vehicula molestie suscipit. Morbi ullamcorper arcu ac ligula dapibus sollicitudin.

JUNIOR POSITION, FIRST JOB — **1994 - 2001**

- Fusce vehicula imperdiet ante eu adipiscing. Donec quam leo, fermentum pretium laoreet sit amet, vehicula in nulla. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas.
- Praesent diam mauris, dictum a tempus ac, faucibus consectetur leo.
- Vestibulum id elit tellus, fermentum hendrerit justo. Mauris nisi ipsum, ultricies non sodales vel, posuere quis tortor.
- Mauris metus tellus, consequat eu dignissim eu, feugiat in metus. Cras id ipsum a sem scelerisque blandit at aliquam eros. Praesent odio urna, dignissim eu malesuada dictum, feugiat ut lectus. Nunc et mi lorem.

EDUCATION:

- Nam in ligula eget erat tempor aliquet. In a pharetra metus.
- Sed consectetur libero sit amet magna pulvinar consequat.
- Aenean rutrum ante id arcu tincidunt id vehicula arcu imperdiet.

— Religious affiliation (unless the position has a religious aspect, such as teaching in a religious affiliated institution).

It is important that your resume stands out.

The Cover Letter or Letter of Application

This is important because it introduces you. Be formal, address how you can be important to your prospective employer, and keep it short but not too short.

Common Mistakes in Cover Letters

- Not checking for spelling, grammar, sentence structure, and that it is addressed to the right employer.
- Making it too short or too long. It should be about 200–250 words (Don't just write "I'm applying for the position of *X*. Please find enclosed my resume and a list of references.") Give reasons why the employer should want to hire you.
- Coming across as arrogant or insecure (or worse—desperate).
- Not knowing about the company that you're applying for. Research the company!

Also, don't include jokes, irrelevant details (e.g., Girl Scout sales successes as a young girl or musical tastes), or criticisms of the prospective or former employees.

Advice from People You Trust

Ask someone you trust to read your resume and cover letter for either a job or internship. If they come back with "it's great" and there are no changes, ask yourself if they have really gone through it carefully or if they are trying to make you feel good, albeit temporarily. Any document can be improved.

Applying Online

Many companies and institutions require online applications. Applicants are advised to do the following:

1. Check out the questions and have draft answers completed and easily available.
2. Have a paper copy of any and all personal information in front of you as you complete the online form.
3. Know where files are located on your computer, including the appropriate resume and references for the specific position.

For each job you apply for, keep a record (electronic and paper) of the name you used and the password you used.

Pay Attention to Responses from a Prospective Employer

Respond quickly to emails or voicemails. You will look enthusiastic and professional. Moreover, you are making the other person's job easier (people like that).

24.4 Reference Letters—Who to Ask and Why

It is recommended that you have about five people who can write positive and informed letters about you as you are now. Possible people can be the instructor of a course you had, the faculty advisor of an undergraduate organization you were active in, your supervisor as a student intern, the faculty member who organized an international experience, and a senior administrator if you are active in student government.

Ensure that the person gets a copy of your unofficial transcripts and resume in sufficient time for them to write the letter and that the person knows you are using them.

24.5 Interviewing

Once you're granted an interview, the hard work of preparing begins. An interview is like a race—you don't win unless you are prepared (see Figure 24.3).

Figure 24.3 An interview is like a race. The swiftest person wins depending on preparation (like training) and thinking about what you are doing. (Source: Pressmaster/Shutterstock)

Preparing for an Interview

In your interview you should demonstrate knowledge about the prospective employer. Make sure you understand the issues facing the company/department, and be able to articulate how you can help it. Visit the company's website and carefully go through the annual report. Also, Google the interviewer along with the name of the company/department. It can be extremely helpful to talk to your network of contacts who know your prospective employer either through work or other interactions.

It is critical to have thought through every aspect of the interview. Give consideration to the following:

- How would you be an asset to the employer?
- What are your strengths that you want the interviewer to see?
- What are your skills and how are they transferable to the prospective position?
- You need to customize your strengths to the employer's needs.
- Think in advance of the likely questions and prepare draft answers.

Check with your college's career center for interview preparation opportunities. It is also essential to be on time, so check to see how long it is going to take to get to the exact location of the interview (at the time of the interview, as traffic conditions vary). It is critical to review your social network presence (e.g., Facebook, LinkedIn, Twitter, Instagram, etc.) and remove any information and pictures that could be embarrassing (use what would embarrass your parents or grandparents as a guide). Avoid political or religious posts. Frequently, human resources departments will check such sites.

Interviewing

Throughout the interview, you want to give the impression that you are professional and competent, are suitable/qualified for the position, would be an asset to the company, would be easy to work with, and are a team player. It is great to be memorable, but not be remembered as the butt of jokes for many years. The last thing you want is for the interviewer to think you are weird. You need to be confident and assertive, while not offending or antagonizing the interviewer.

The first essential is showing up on time. Allow yourself enough time so that if anything goes wrong you won't be late for the interview. On the other hand, you should be no more than 10 minutes early for the appointment. If you are very early, find a coffee shop near the interview site to relax and mentally prepare yourself.

Your appearance is the first impression that you make. This applies to a campus interview or Skype/video interview. Not only should you be dressed appropriately and professionally for an interview, but your clothes should also be clean and pressed and your shoes polished. Moreover, your hair should be brushed/combed, your face and hands washed, and your teeth clean. Give yourself enough time before the interview for a bathroom visit. This is recommended for the obvious reasons but also to check your appearance. It is usually a good idea to have any tattoos and piercings covered. When the time comes, greet the interviewer with a smile and a firm handshake (see Figure 24.4).

> Regardless of how you feel inside, always try to look like a winner. Even if you are behind, a sustained look of control and confidence can give you the mental edge that results in victory.
>
> —Arthur Ashe (1943–1993),
> American professional tennis player

Figure 24.4 As you enter the room for your interview, shake hands with the interviewer(s) with a firm handshake (not a "dead fish" or "bone crusher" or "two-handed/hand-hug" handshake). Look the interviewer in the eyes and clearly say "good morning" or "good afternoon."

Textbox 24D

Tips for Interviewing

- Be prepared! Do your homework before the interview.
- Timeliness—be punctual.
- Know where you are interviewing. Do a trial journey to the interview site if possible.
- Be at the location of the interview 30 minutes early (giving a time buffer in case of travel problems). If at a building, be at the specific office of the interview 10 minutes early.
- Turn off your cell phone before you enter the building.
- Use the bathroom for the obvious and to wash and dry hands thoroughly. (You don't want to have clammy hands.)
- Walk confidently into the interview room (no slouching).
- Shake hands (firm handshake) with all the interviewers, looking them in eyes (see Textbox 24D Figure 1).
- Have a professional disposition and posture (no slouching).
- Provide short, honest answers to questions.
- Be prepared with thought-out answers ("elevator speeches") but appear to be spontaneous (not memorized answers).
- Send a thank-you note. **Make sure you spell the interviewer's name right.** Your response can include amplifications on responses.

Textbox 24D Figure 1 A candidate for a job interview introducing himself with a firm handshake, making eye contact, smiling, and providing a copy of his resume in case it is needed. (Source: Antonio Guillem/Shutterstock)

Answering Questions and What Questions to Expect

The interviewer can ask you virtually anything, although there are some questions that should not be asked, such as age and marital status. The most likely first questions are "tell me about yourself" or "why are you applying for this position?" These are questions that you should have an answer ready for. You should have thought about the likely questions beforehand. Prepare yourself by planning, researching, and giving thoughtful consideration to all aspects of the position you are applying for. This gives you the opportunity to make a great first impression by appearing professional with a knowledge of the company/university/agency and that your talents meet their needs. Throughout the interview, call attention to your accomplishments and future direction. Customize your answers based on your knowledge of the prospective employer. Be as specific and succinct as possible. Be honest, but do not volunteer information that may be disadvantageous to you. For a difficult question that you have not thought about, you may need time to think. You can pause or repeat back the question (such as "my understanding of your question is that you are asking . . .") or ask the interviewer to clarify the question. These approaches give you more time to carefully consider your answer. However, do not use this approach too often.

Remember, an interviewer may ask you an off-the-wall question to see how you will react or because they are not an experienced interviewer. They may also be silent after you've finished your answer in an attempt to get you to volunteer information disadvantageous to you. A response to silence is to ask the interviewer if there are areas that you can elaborate on. Watch the interviewer for nonverbal cues. Do they look like they are getting impatient? If they appear to like you, it is advisable to then be more cautious lest you present yourself as overconfident or even arrogant.

A list of some other likely questions including the following:

- What can you do that would help us?
- Give an example of a difficult situation and how you dealt with it. (Note: Remember that your answer must put you in a positive light and not break confidentiality.)
- Give an example of a difficult person and how you dealt with them. (Note: Again, remember your answer must put you in a positive light and not break confidentiality.)

- What would you accomplish in the first month or 90 days if you get the position?
- What do you think are attributes of the most successful people?
- If you get the job, where do you want to be in five years? (Note: Do not give a trite answer such as, "If this is Wednesday afternoon, I hope to be on the golf course." This was an actual answer given by an unsuccessful candidate.)
- Give an example of a goal you set for yourself, or someone else set for you, and how you accomplished it.

TEXTBOX 24E

Additional Questions You Might Be Asked at an Interview

1. Tell me about yourself.
2. Why are you applying for this position?
3. How did you hear about the position?
4. What are the major features of this company/department?
5. What can you do that would help us?
6. What did you achieve in your present/last position?
7. What was a difficult situation at school, or in your present position, and how did you deal with it?
8. What are three strengths you don't have?
9. What do you think are some challenges you will face if appointed?
10. What do you do in your spare time?
11. What are your best strengths/characteristics?
12. What are your worst characteristics?
13. What other positions have you applied for/are interviewing for?
14. Have you been terminated in any positions and if so why?
15. Why is there a gap in employment?
16. How do you deal with stressful situations?
17. If you were an animal, what would you be and why?
18. What was the last book you read?
19. What is your favorite movie and why?
20. Do you have any questions for us?
21. What are your salary expectations?
22. What's your salary history?

Trick Questions

1. Tell me about yourself.
   This is your chance to give your "pitch" or "elevator speech."
2. What do you do in your spare time?
   They are wondering how you will fit in. Is there a softball or bowling league at the company? If you like softball or bowling, mention it. Avoid answers that make you appear unprofessional, such as partying. Avoid answers, particularly lengthy ones, about religious or political activities.
3. What are your worst characteristics?
   Avoid bearing your soul. This is an interview, not a session with a therapist. Your answers should project your suitability for the position, such as "I am too focused on getting the job done right and on time" or "I am too loyal to my employer."
4. What was a difficult situation at school, or in your present position, and how did you deal with it?
   This is an opportunity to shine. Describe the situation briefly and then your role in resolving it successfully. Do not break confidences or bad mouth present or past employers or your academic department.
5. Do you have any questions for us?
   This is your opportunity to demonstrate your intelligence and show that you have researched the company or department. It also gives you the opportunity to find out (carefully) what is going on. You might also like to schmooze by asking something like "what do you like about working here?"
6. If you were an animal, what would you be and why?"
   Random questions are another opportunity to mention your strengths. An answer could be "an eagle—not only because I want to soar but because I am always alert, watching for opportunities, and problems that need resolving."
7. What are your salary expectations?
   This can be difficult. You have to answer based on research but also demonstrate flexibility.

Illegal Questions (But Still Asked)

1. What is your age?
2. What is your marital status?
3. What is your ethnic background or national origin?
4. What is your sexual orientation?
5. How many children do you have?
6. When do you anticipate starting a family?
7. What is your religion?

These can be addressed by answering the question or returning the discussion to the position you are applying for.

- What three words describe you?
- What do you think colleagues/faculty would say about you?
- How do you manage your time?
- What are your strengths and weaknesses? (Note: This is not a confession. Try to state strengths as weaknesses, such as "people say I work too hard or I care too much about my employer or I'm too focused on accomplishing the task.")
- How do you deal with pressure?
- Describe a typical work week. (This is particularly relevant for someone who was an intern.)
- Where would you like to be professionally in five or ten years?
- For senior positions—what's your leadership style? It is important to know the jargon about different leadership styles and how you fit.

When asked if you have any questions it is not a good idea to say "no." This is your last opportunity to present yourself to the interviewer. Think about this before the interview. Questions you might ask include the following:

- What are your expectations for the person who is hired?
- What are the long-term goals for the department?
- What are the opportunities for professional development?
- What are the opportunities for training and further education?

At the end of the interview, ask if you could briefly summarize your strengths and then do so. Leave the interview with a smile and a handshake.

TEXTBOX 24F

"Dos" and "Don'ts" for Interviewing

The "Dos"

- Look confident.
- Practice in front of a mirror.
- Dress appropriately.
- Use a firm handshake and look the interviewer in the eyes.
- Sit up straight and be alert.
- Make eye contact regularly. (If you feel uncomfortable looking someone in the eyes, you might try looking about an inch above the eyes. Apparently, people can't tell the difference.)
- Keep your responses clear and to the point.
- Answer questions honestly but in a manner that makes you look as good as possible but not in a way that "torpedoes" the interview.
- Have "elevator speeches" (one to two minutes in length) ready for the obvious questions such as "Tell me about yourself" or "Why are you applying for this position?"
- Show respect for yourself and the interviewer throughout the interview. Switch off your cell phone beforehand.
- Smile and show your interest in the position.
- End by thanking the interviewer (followed by sending a thank-you note).

The "Don'ts"

- Do not have a limp handshake (the "dead-fish handshake") or overly firm handshake (the "bone-crusher" handshake).
- Do not be overconfident or presumptuous.
- Do not criticize your family, your university, previous employers, and particularly the company/organization interviewing you.
- Do not look bored. Do not check your watch as if you'd rather be somewhere else.
- Do not joke or reveal unprofessional aspects of your life (e.g., awkward nicknames, times partying, etc.).
- Do not chew gum or tobacco.
- Do not smoke.
- Do not pick or touch your face or other body parts.
- Do not discuss salary or benefits unless the interviewer brings them up.
- Do not bring someone with you. Your mother, father, girlfriend, boyfriend, partner, or spouse are probably wonderful people but their presence at an interview sends the message that you are not an adult or you are needy.
- Don't go to an interview wearing inappropriate footwear (you're not going to the beach or on a date).

Advice for Interviewing

During the interview remember the adage "sit up, speak up, and then shut up!" Project confidence and speak powerfully but with brevity.

William Shakespeare wrote in *Hamlet*, "For the apparel oft proclaimes the man" or "Clothes make the man (or woman)."

TEXTBOX 24G

What to Wear at an Interview

Depending on the company, you should wear either business professional attire or business casual attire. If in doubt, first check with the company or department. However, if you are not sure, tend to the more formal.

Business Professional Attire

Examples of professional attire are shown in Textbox Figure 24G Figure 1A.

Women

- Business suit (dark blue, black, pin-stripe, dark brown, or grey) with either a skirt or pants.
- A white or light-colored blouse.
- Minimal jewelry.
- Neutral hose.
- Small purse or bag.
- Conservative shoes (clean).

Men

- A dark business suit (dark blue, black, pin-stripe, dark brown, or grey).
- A white or light-colored shirt.
- Business-type tie (reaching the belt).
- Dark socks (calf-length) of complimentary color to suit.
- Conservative shoes of complimentary color (clean).

Business Casual Attire

Examples of business casual attire are shown in Textbox Figure 24G Figure 1B.

Women

- Tailored pants or dress (skirt no more than one inch above the knee).
- Colored blouse.
- Blazer (maybe) or sweater.
- Moderate jewelry.
- Relatively conservative shoes (clean).

Men

- Tailored pants (e.g., khakis or solid-colored pants)
- Belt.
- A white or light-colored dress shirt (or, depending on the company, a polo shirt).
- Blazer (maybe) or sweater.
- Business-type tie (maybe).
- Oxfords or loafers (clean).

For both men and women, avoid jeans or shorts and backpacks. For men, avoid double-breasted jackets. For women, avoid clothing like low-cut dresses, short skirts, very high-heeled shoes, open-toed shoes, or capris.

A

B

Textbox 24G Figure 1 Look the part: young professionals in more formal business (A) or business casual attire (B). (Sources: Monkey Business Images/Shutterstock and sirtravelalot/Shutterstock)

Textbox 24H

"Dos and Don'ts" of a Meal as Part of an Interview

The "Dos"

- Appear professional and confident at all times.
- Be punctual.
- Keep your cell phone switched off.
- Shake hands (in a firm manner) with everyone you are having dinner with.
- Dress professionally. Remember it is better to overdress than underdress.
- Have good table manners.
- Smile and appear interested in the conservation (see Textbox 24H Figure 1)
- Let the other people talk but make sure your contribution to the conversation is appropriate for the size of the group (25–35% if it is you and three interviewers).
- For a poultry position, eat chicken, turkey, or duck. (For a livestock-related position, eat the relevant meat if possible).
- Use your napkin.
- Be polite (e.g., thank the server).
- Use "sir" and "ma'am" when appropriate.

Textbox 24H Figure 1 Remember that during a meal interview you are still being evaluated. You can easily talk yourself out of the position by what you say or do. Be pleasant and engaged but in control of yourself while your prospective colleagues enjoy the night out. (Source: iofoto/Shutterstock)

The "Don'ts"

- Do not drink alcoholic beverages. However, if everyone else does, go ahead and order one. Use it for toasts and sip it and drink plenty of water.
- Do not eat garlic or anything else that will affect your breath.
- Do not eat messy foods, such as pasta and tomato sauce, ribs, or messy sandwiches.
- Do not appear humorless but do not make jokes, particularly of a sexual, religious, political, or racial nature.
- Do not slouch (see Textbox 24H Figure 2).
- Do not use profanity, even if the interviewer does.
- Do not chew gum or tobacco.
- Do not smoke.
- Do not pick or touch your face or other body parts.

Textbox 24H Figure 2 There are activities that you should not do during an interview. For example, don't chew gum and don't look bored with the interviewer. (Source: LightField Studios/Shutterstock)

TEXTBOX 24I

Discussion Questions

1. What are your reasons for considering a particular career?
2. How do extracurricular activities help on a resume?
3. How do research experiences and/or international experiences help during a job search?
4. What are the advantages or disadvantages of internships?
5. What are the advantages or disadvantages of graduate school or professional school?
6. What are the ethics of writing resumes?
7. What are the ethics of interviewing?
8. Why be as positive as possible in the interview?
9. What aspects of body language make you appear open, honest, and friendly?
10. Why should you not lie or embellish your record or resume?

24.6 Internships

Internships can offer an applicant a tremendous advantage and can lead to a full-time position. Employers usually view internships positively because they often bring intelligent and enthusiastic young people to a company (Figure 24.5). The company can also select someone who fits the company culture and brings recognizable talents that will benefit them. An internship is a time for an employer to know whether the intern would make a good, or even great, employee. It is also the time when the intern can evaluate whether the job and company is something that he or she would like long term. Some might view an internship like a 3-, 6-, or 12-month interview. There are many advantages of internships:

- Experience.
- Building a resume.
- Networking.
- Having people who know you well and can write a good letter of recommendation.
- Providing something to talk about at interviews (while maintaining confidentiality), as well as a competitive edge over other candidates.
- You can get to know a prospective employer and work environment, and the employer gets to know you.

Figure 24.5 Internships provide an opportunity to develop skills such as problem solving and working in teams. (Source: Monkey Business Images/Shutterstock)

Check with your school's career counseling center and your advisor to get a list of companies (together with the name of the contact person and their address/email address) that offer internships. Once you have the list, you need to do some research on the company to gain an initial insight of what they may want and how you might be useful to the company.

24.7 Professional School/ Graduate School

Why Attend Graduate School?

For many careers, a graduate degree is very useful, and, in some cases, essential. For instance, if you are considering a career in business, a Master of Business Administration (MBA) degree is excellent training, particularly if you want to be a "high flyer" (someone who moves up, often rapidly, within an organization). For a career in research, education, and much of government, a graduate degree is either required or strongly recommended.

A master's degree is recommended for people considering a career in the sciences, such as a laboratory technician, extension agent, educator/instructor (at a two-year college), nutritionist, or geneticist. A doctorate (PhD) is required for someone wanting a career as a research leader (in a company or government laboratory, e.g., USDA, CDC, FDA, etc.), or a faculty member, irrespective of whether teaching and/or research and/or extension.

Advice When Applying

The choice of a graduate program and graduate school comes down to the following:

- What is available that meets your needs?
- What is the reputation of the program/school?
- Are you happy to live in the place where the program is offered (two years for a masters and five years for a doctoral program)?
- What financial support is available?

We will address program quality first. Assuming the program meets your needs, the most important consideration is the quality of the program/school, as you will be known by the program for the rest of your career. For doctoral studies, the reputation of the advisor/major professor is also very important. You will be known as that person's academic "son" or "daughter" for your entire career. Working with someone with an outstanding reputation will stand you in good stead. However, it is also critically important to have a research advisor/major professor that you can work with. Do not hesitate to email individual people you'd like to do research with.

There are also assistantships available for some master's programs and virtually all doctoral programs. These vary in size, whether tuition is covered, and whether there are health benefits attached. Another consideration is the cost of living in the area.

How to Apply

Many graduate programs require applicants to have taken the Graduate Record Examination (GRE). Graduate applications include unofficial transcripts and GPA, GRE scores, and an application with an essay. It is really useful to have undergraduate research experience to add interesting points to your essay (see Figure 24.6).

Advice for Applications for Research Masters and PhD Programs

You need to show that you know about the laboratory, department, or program that you're applying for. Do your research about them before applying. You should consider the following:

- Is there a good fit with the laboratory, department, or program that you're applying? If yes, why?
- Are you likely to succeed and be a credit to the laboratory, department, or program that you're applying?
- In what ways have your experiences and curriculum prepared you for the laboratory, department, or program that you're applying?
- Does the quality of the laboratory, department, or program meet both your aspirations and your abilities?
- Does the location work for you? If you want to be within 100 miles of your family, a place 1,000 miles away is not necessarily a good idea. If you like oceans, the Midwest may not be the optimum choice. If you like rural life, an urban school may not the best place to go or vice versa.

Figure 24.6 Research adds considerably to a student's resume. (Source: Likoper/Shutterstock)

Why Earn a Professional Degree?

Many students who take a degree in poultry science have a burning desire to go to veterinary school. This is a laudable goal. Not everyone is accepted to veterinary school; in fact it is very competitive to be accepted. Grades are one of the most important considerations, particularly grades in specific courses. The Veterinary Medical College Application Service (VMCAS) is a system for applying to accredited colleges in the United States and elsewhere. Some schools require GREs or MCATs. Students with a degree in poultry science or animal science take classes that are required or recommended for admission to veterinary medicine. Such classes include anatomy, physiology, and biochemistry.

There is a need for veterinarians, particularly with an interest in poultry diseases or avian pathology (or large animal veterinary medicine). For university faculty positions in veterinary schools, it is advantageous to have both a Doctor of Veterinary Medicine (DVM) and a PhD. Some veterinary programs have systems to facilitate completion of both degrees at the same time.

24.8 Applying for a Faculty Position

It is suggested that you read the entire chapter because there is useful information about various positions. This section covers specific additional advice to people applying for faculty positions.

Application

Your application for a faculty position should include a curriculum vitae, teaching philosophy, research program, cover letter, and list of references.

Curriculum Vitae versus Resumes

The curriculum vitae should include everything you have done that is relevant to an academic position. It starts with name and address (plus email address and telephone numbers); followed by awards and honors; committees, including roles; classes taught, with level; student numbers and student evaluations; undergraduate, MS, and doctoral students who have worked with you; grants/contracts; editorial boards/editorships; publications; invited presentations at international conferences and symposia; presentations/abstracts; any consulting; extension presentations; and presentations to producers and companies. Being invited to give presentations at international symposia and conferences can add considerable value to your curriculum vitae and academic reputation (see Figure 24.7).

Cover Letter

The cover letter needs to include why you are applying and how your skills and background fit what is required.

Research Plan

A research plan should be about 2.5 pages long (single spacing but with subheadings). This is similar to what goes into a federal grant. You need to think both forward and backward. Based on what you are doing now, where is it leading? Also, where would you like your research to be in five years and how do you get there? Ensure that the research plan is consistent with the specific position you are applying for.

Figure 24.7 Presentations at international professional symposia or conferences enhance your academic reputation. Be memorable but for good reasons. (Source: Matej Kastelic/Shutterstock)

Teaching Philosophy

This is important because it shows you have thought about the position. It needs to encompass the pedagogies you employ, your teaching goals, and objectives for both undergraduate and graduate education. You might include examples of successes (both yours and of the students) and lessons learned. The teaching philosophy should be 1.5–2.5 pages long (single spacing but with subheadings). Ensure the teaching philosophy is consistent with the specific position you are applying for.

References

You need 3–5 references with addresses (plus email addresses and telephone numbers). The people should know you well and be willing to write a good reference. For first faculty positions, your major professor and post-doctoral advisor should be on the list.

Preparing for the Interview

Print off the schedule as soon as you get it and prepare for each meeting. Think about your actions/questions/statements for every part of the schedule. People will compare notes before or after you leave. They are looking for a colleague and someone who can help the department. Have your seminar prepared.

The Interview

Key issues:

- The interview starts when you are picked up at the airport and ends when you are dropped off at the airport.
- All meetings are important.
- Don't disparage. This includes, but is not limited to, your present institution or employer together with the department head or major professor.

The Seminar

Remember the following basic rules:

- Use PowerPoint (some university computer systems do not allow use of Keynote).
- Have the presentation on a flash drive and email it to yourself.
- Have paper copies of the presentation with you.
- Slides should be readable and changed about one per minute.
- Inspect slides for images that might be viewed as racist, sexist, or homophobic.

If you are scheduled for 45 minutes plus questions, it is awkward to go for 35 minutes or less or for more than 50 minutes. After 60 minutes you may have talked yourself out of a position. Follow up with email thank-you letters.

Appendix I

Poultry Breeds

The American Poultry Association (APA) Breeds and Varieties

The American Poultry Association (APA) was founded in 1873. The APA sanctions breed and variety standards and competitions at poultry shows in North America. In addition, the APA advocates for raising "standard-bred" poultry (from a single breed or variety) and certifies poultry using the "APA Certified" label. These are also marketed as heritage breeds or varieties. Other considerations for heritage labeling are that breeding was by natural means (not artificial insemination) and the birds spent part of their lives outdoors.

Chickens

The accepted breeds and varieties of large chickens and bantam chickens are shown in tables 1 and 2, respectively. The classes of large chickens are American, Asiatic, Continental, English, and Mediterranean. These reflect where the breeds were developed. Breeds differ in the colors of their plumage (see Appendix I Table 1), shank, ear lobes, skin, and eggs, as well as the presence of shank feathers, number of toes, and comb type.

Appendix I Table 1 Breeds and varieties of large chickens.

Class	Breed	Varieties
American	Buckeye	Only one variety
	Chantecler	White, Partridge
	Delaware	Only one variety
	Dominique	Only one variety
	Holland	Barred, White
	Java	Black, Mottled
	Jersey Giant	Black, White, Blue
	Lamona	White
	New Hampshire	Only one variety
	Plymouth Rock	Barred, White, Buff, Silver Penciled, Partridge, Columbian, Blue
	Rhode Island Red	Single Comb and Rose Comb
	Rhode Island White	Rose Comb
	Wyandotte	Silver Laced, Golden Laced, White, Black, Buff, Partridge, Silver Penciled, Columbian, Blue
Asiatic	Brahma	Light, Dark, Buff
	Cochin	Buff, Partridge, White, Black, Barred, Silver Laced, Golden Laced, Blue, Brown
	Langshan	Black, Blue, White

(continued)

Class	Breed	Varieties
Continental	Barnevelder	Only one variety
	Campine	Silver, Golden
	Crèvecoeur	Black
	Faverolles	Salmon, White
	Hamburg	Golden Spangled, Silver Spangled, Golden Penciled, Silver Penciled, Black, White
	Houdan	Mottled, White
	La Flèche	Black
	Lakenvelder	Only one variety
	Marans	White, Black Copper, Wheaten
	Polish—Bearded	Golden, Silver, White, Buff Laced
	Polish—Non-Bearded	White Crest Black, Golden, Silver, White, Buff Laced, White Crested Blue, Black Crested White
	Welsummer	Only one variety
English	Australorp	Black
	Cornish	Dark, White, White-Laced Red, Buff
	Dorking—Single Comb	Silver Gray, Colored, Cuckoo, Red
	Dorking—Rose Comb	Cuckoo, White
	Orpington	Buff, Black, White, Blue
	Redcap	Only one variety
	Sussex	Speckled, Red, Light
Mediterranean	Ancona	Single Comb and Rose Comb
	Andalusian	Blue
	Catalana	Buff
	Leghorn—Rose Comb	Dark Brown, Light Brown, White, Black, Buff, Silver
	Leghorn—Single Comb	Black, Dark Brown, Light Brown, White, Buff, Silver, Red, Black-Tailed Red, Columbian, Golden
	Minorca—Single Comb	Black, White, Buff
	Minorca—Rose Comb	Black, White
	Sicilian Buttercup	Only one variety
	Spanish	White Faced Black
All other breeds	Ameraucana	Black, Blue, Blue Wheaten, Brown Red, Buff, Silver, Wheaten, White
	Araucana	Black, Black-Breasted Red, Golden Duckwing, Silver Duckwing, White
	Aseel	Black-Breasted Red, Dark, Spangled, Wheaten, White
	Cubalaya	Black, Black-Breasted Red, White
	Malay	Black, Black-Breasted Red, Red Pyle, Spangled, Wheaten (female), White
	Modern Game	Birchen, Black, Black-Breasted Red, Brown Red, Golden Duckwing, Black, Red Pyle, Silver Duckwing, Wheaten, White
	Old English Game	Black, Crele, White, Spangled, Self Blue, Red Pyle, Brown Red, Lemon Blue, Black-Breasted, Red, Blue-Breasted Red, Blue Golden Duckwing, Blue Silver Duckwing, Golden Duckwing, Silver Duckwing
	Naked Neck	Black, Buff, Red, White
	Phoenix	Golden, Silver
	Shamo	Black, Dark, Black-Breasted Red, Wheaten
	Sultan	White
	Sumatra	Black, Blue
	Yokohama	Red Shoulder, White

Appendix I Table 2 Breeds and varieties of bantam chickens.

Class	Breed	Varieties
AOCCL (All Other Comb Clean Leg)	Cornish	Black, Blue Laced Red, Buff, Dark, Mottled, Spangled, White, White-Laced Red
	Crèvecoeur	Black
	Cubalaya	Black, White, Black-Breasted Red
	Houdan	Mottled, White
	KO Shamo	Wheaten
	La Flèche	Black
	Malay	Black, Black-Breasted Red, White, Red Pyle, Spangled, Wheaten (female)
RCCL (Rose Comb Clean Leg)	Dominique	Only One Variety
	Dorking—Rose Comb	White
	Hamburg	Black, Golden Penciled, Golden Spangled, White, Silver Penciled, Silver Spangled
	Leghorn—Rose Comb	Black, Buff, Dark Brown, Light Brown, Silver, White
	Minorca—Rose Comb	Black, White
	Nankin	Only One Variety
	Redcap	Only One Variety
	Rhode Island Red	Only One Variety
	Rosecomb	White, Blue, Black
	Sebright	Silver, Golden
	Wyandotte	Black, Blue, Buff, White, Columbian, Buff Columbian, Silver Laced, Golden Lace, Silver Penciled, Partridge
SCCL (Single Comb Clean Leg)	Delaware	Only One Variety
	Dorking—Single Comb	Silver Gray, Colored
	Dutch	Black, Silver, Blue Cream Light Brown, Light Brown, Blue Light Brown, Cream Light Brown
	Holland	Barred, White
	Japanese	Barred, Black, Black Tailed Buff, Black Tailed White, Brown Red, Gray (Birchen), Mottled, Wheaten, White
	Java	Black, Mottled
	Jersey Giant	Black, White
	Lakenvelder	Only One Variety
	Leghorn—Single Comb	Barred, Black, Black-Tailed Red, Buff, Columbian, Red, Dark Brown, Golden, Light Brown, Silver, White
	Minorca—Single Comb	Black, Buff, White
	Naked Neck	White, Buff, Red
	Nankin	Only One Variety
	New Hampshire	Only One Variety
	Orpington	Buff, White, Blue, Black
	Phoenix	Golden, Silver
	Plymouth Rock	Barred, Black, Blue, Buff, Columbian, Partridge, White, Silver Penciled, Black Frizzle
	Rhode Island Red	Only One Variety
	Spanish	White Faced Black
	Sussex	Light, Red, Speckled
	Welsummer	Partridge
Feather Legged	Faverolles	Salmon, White
	Langshan	Black, Blue, White
	Silkie (Non-Bearded)	Black, Buff, Gray, Partridge, White
	Silkie (Bearded)	Black, Blue, Buff, Gray, Partridge, Splash, White
	Sultan	White

(continued)

Class	Breed	Varieties
Game Class	Old English Game	Black, Birchen, Blue, Brassy Back, Brown Red, Crele, Columbian, Cuckoo, Ginger Red, Blue Brassy Back, Blue-Breasted Red, Blue Golden Duckwing, Blue Silver, Duckwing, Fawn Silver Duckwing, Black-Breasted Red, Black Tailed Buff, Golden Duckwing, Lemon Blue, Mille Fleur, Quail, Red Pyle, Self Blue, Silver Blue, Silver Duckwing, Spangled, Wheaten, White, Blue Wheaten
Modern Game	Modern Game	Black, Blue, Birchen, Red Pyle, Splash, Wheaten, Black-Breasted Red, Blue-Breasted Red, Brown Red, Golden Duckwing, Lemon Blue, Silver Blue, Silver Duckwing
White	Lamona	White


A. Barred Plymouth Rock


B. Black Giant or Jersey Giant


C. Blue-Laced Red Wyandotte


D. Dominique


E. New Hampshire


F. Rhode Island Red

Appendix I Figure 1 American breeds of chickens. (Sources: A. Jena Fuller/Flickr; B. C. D. F. Courtesy of Murray McMurray Hatchery; E. Fxnick/Wikimedia Commons.)


A. Black Langshan


B. Buff Brahma


C. Light Brahma

Appendix I Figure 2 Asiatic breeds of chickens. (Sources: A. B. C. Courtesy Murray McMurray Hatchery.)


A. Campine


B. Crèvecoeur


C. Hamburg


D. La Flèche


E. Polish

Appendix I Figure 3 Continental Breeds. (Sources: A. Cirasa Giovanni/Wikimedia Commons; B. Blaise.desaintjouin/Wikimedia Commons; C. Joe Mabel/Wikimedia Commons; D. Édouard Hue/Wikimedia Commons; E. Just chaos/Wikimedia Commons.)


A. Black Australorp


B. Buff Orpington


C. Dark Cornish


D. Sussex


E. Silver Grey Dorking

Appendix I Figure 4 English breeds of chickens. (Sources: A. B. C. D. E. Courtesy of Murray McMurray Hatchery.)

A. Ancona

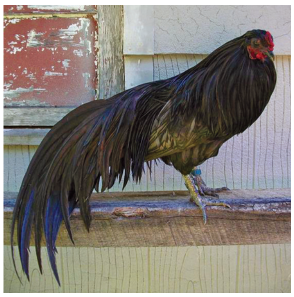
B. Andalusian Blue

C. Brown Leghorn

D. Single-Comb White Leghorn

E. Minorca

Appendix I Figure 5 Mediterranean breeds of chickens. (Sources: A. Festina lente/Wikimedia Commons; B. D. Courtesy of Murray McMurray Hatchery; C. E. Courtesy Wikimedia Commons.)



A. Sumatra

B. Yokohama

Appendix I Figure 6 Other breeds of chickens. (Sources: A. B. Courtesy of Murray McMurray Hatchery.)

Color of Shank

- **White:** Buff Orpingtons, Dorkings, Sussex.
- **Yellow:** Anconas, Cochins, Leghorns, New Hampshires, Rhode Island Reds, White Plymouth Rock, Wyandottes.
- **Dark grey/black:** Andalusians, Australorp, Cornish, Jersey Black Giants, Minorca.

Ear Lobe Color

- **Red:** Australorp, Buff Orpingtons, Cochins, Cornish, Dorkings, Jersey Black Giants, New Hampshires, Rhode Island Reds, Sussex, White Plymouth Rock, Wyandottes.
- **White:** Andalusians, Anconas, Leghorns, Minorca.

Skin Color

- **White:** Andalusians, Australorp, Orpingtons, Dorkings, Minorca, Sussex.
- **Yellow:** Anconas, Cornish, Cochins, Jersey Black Giants, Leghorns, New Hampshires, Rhode Island Reds, White Plymouth Rock, Wyandottes.

Egg Color

- **White:** Andalusians, Anconas, Catalanas, Dorkings (Silver grey), Hamburgs, Lakenvelders, Leghorns, Minorcas, Polish, Sultans, Sumatras and Yokohamas.
- **Brown:** Australorps, Brahmas, Buff Orpingtons, Cochins, Cornish, Delawares, Dominiques, Jersey Black Giants, Langshans, New Hampshires, Sussex, White Plymouth Rock, Rhode Island Reds and Wyandottes.
- **Blue:** Araucana (from Chile), Ameraucanas, Cream Legbar, the Dongxiang (China) and Lushi (China) breeds.

Shank Feathers

- Shank feathers are usually found only in Brahmas, Cochins, and Langshans.

Number of Toes

All have four toes except Dorkings, which have five toes.

Type of Comb

- **Single:** Andalusian, Australorp, Cochin, Dorking, Jersey Giant, Langshan, Minorca, New Hampshire, Orpington, Plymouth Rock, and Sussex.
- **Pea:** Brahma, Cornish.
- **Rose:** Wyandotte.
- **Single or Rose:** Ancona, Leghorn, Rhode Island Red.

A Deeper Dive into Breeds of Chickens

European Landrace Breeds

A **landrace** breed is developed in specific regions over centuries of effective isolation.

- **Andalusians** are from Andalusia, a province within Spain.
- **Crèvecoeur** are a French breed named for the town of Crèvecoeur in Normandy.
- **Dorkings** (five-toed) were found in Southeast England and named for the town of Dorking, Surrey, England. It is thought that the Romans brought Dorkings to England over 1800 years ago.
- **Minorcas** originated from Castile in Spain, although they are named after Minorca, the island in the Mediterranean Sea.
- **Spanish** originated from Spain and were imported to the US in about 1825.
- **Sussex** chickens are an old breed found in Sussex, England, and possibly introduced to England by the Romans over 1800 years ago.

Possible Landrace

- **Polish** originated from Eastern Europe, specifically Poland.

Asian Landrace Breeds

- **Malay** originated from Southeast Asia.
- **Sumatras** are from the Island of Sumatra (Indonesia).
- **Langshan** originated from a district in China located near the Yangtze River, about 100 miles from Shanghai.

Possible Landrace

- **Javas** are possibly from the Island of Java (Indonesia)

Breeds Imported

- **Brahma** originated in China but is named after the Brahmaputra River in India.
- **Cochins** originated in China (the name comes from a Chinese word), coming to the US from the port of Shanghai.
- **Hamburgs** were imported to the US possibly from the German port of Hamburg. The birds originate from the Netherlands.
- **Leghorns** originated from Tuscany, in central Italy. They were imported to the US from the port of Livorno in the mid-1800s. The city name was anglicized to Leghorn. It is an excellent egg layer. It was the basis of the Loony Tunes character Foghorn Leghorn.

Breeds Developed in the US and Canada

- **Delawares** [dual purpose] originated in the US state Delaware in the 1940s from crosses between Barred Plymouth Rocks and New Hampshires.
- **Dominiques** [dual purpose] were developed in New England from crosses between multiple breeds including Sussex, Dorkings, and probably also Asiatic breeds. Easy names include the Old Grey Hen and Dominicker.
- **Jersey Giants or Jersey Black Giants** [meat] were developed in New Jersey around 1875 from crosses between Black Javas and Black Langshans, together possibly with Black Orpingtons and/or Dark Brahmas.
- **New Hampshires** [dual purpose] were selected from Rhode Island Red stock in the US state New Hampshire in the early 1900s.
- **Plymouth Rocks** [dual purpose] were developed in about the 1850s in Massachusetts. The breed is believed to be based on crosses of Brahma, Cochin, Dominique, Java, and Spanish chickens.
- **Rhode Island Reds** [dual purpose] were developed in Rhode Island and Massachusetts between about 1850 and 1890. The breed was developed from Malay, Java, and Leghorn chickens.
- **Wyandottes** [dual purpose] were developed in upstate New York and Ontario in the 1800s. They are named after a Native American tribe.

Breed Developed in Australia

- **Australorps** were developed in Australia in the early 1900s from Black Orpingtons with out-crossings to Rhode Island

Reds, Minorcas, White Leghorns, and Langshans. It is a dual purpose bird and an excellent egg layer.

Breed Developed in France

- **La Flèche** were developed in the Loire region of France reputedly in about 500 AD.

Breed Developed in Italy

- **Ancona** were developed in Italy, possibly from Leghorns and other breeds.

Breed Developed in Germany

- **Yokohama** were developed in Germany between the 1880 and 1920, crossing male Yokohamas with Malay game fowl and Sumatras.

Breeds Developed in the United Kingdom

- **Cornish** (previously the Indian Game or Cornish Indian Game breed) were developed around 1820 in Cornwall, England. They are thought to have some Malay genetic background from crosses of Red Aseel and Black-Breasted Red Game chickens.
- **Orpingtons** were developed in Kent, England, in the 1880s from crosses of Minorcas, Langshans, and Plymouth Rocks.

Turkeys

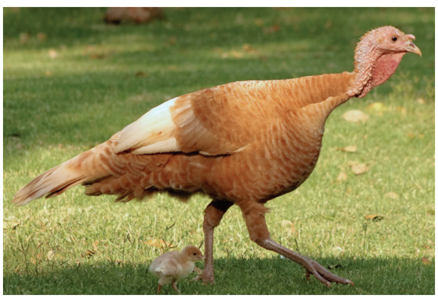
The American Poultry Association (APA) accepts only eight varieties of turkeys into its Standard of Perfection: Beltsville Small White; Black (or Black Spanish); Bronze or Standard Bronze; Bourbon Red (developed in Bourbon county, Kentucky); Narragansett (thought to be developed in the area around Narragansett, Rhode Island, by crossing domestic and wild turkeys); Royal Palm; Slate (or Blue Slate); and White Holland (thought to be derived from Bronze turkeys.). These are all considered heritage varieties (sometimes heritage breeds). In addition, other varieties are the Jersey Giant and White Midget (sanctioned by the American Livestock Breeds Conservancy), Crimson Dawn, Calico, and Red Phoenix. There are other varieties, such as the Chocolate (see Appendix I Figure 7). Lines for commercial turkey production were developed from broad-breasted varieties like the Standard Bronze, White Holland, and Beltsville Small White.

A. Beltsville Small White breed

B. Black Spanish

C. Chocolate

D. Bronze tom



E. Bronze hen

F. Narragansett

G. Royal Palm Turkey

Appendix I Figure 7 Heritage and rare varieties of turkeys. (Sources: A. USDA Agricultural Research Service/Wikimedia Commons; B. C. Courtesy of Murray McMurray Hatchery; D. Amy McNabb/Shutterstock; E. Snap2Art/Shutterstock; F. Nancy Kennedy/Shutterstock; G. Shutterstock photo by Sonia Horowitz)

Ducks and Geese

The accepted breeds and varieties of ducks and geese are listed in Tables 3 and 4. Figures 8 and 9, respectively, show breeds of domesticated ducks and geese.

White Pekin or Pekin

White Pekin ducks are large white-feathered birds (see Figure 22.4). Adult drakes weigh 9 lb (~4 kg) and adult females weigh 8 lb (3.6 kg). They have orange-yellow bills, reddish-yellow shanks and feet, and yellow skin. Their eggs are tinted white. The breed originated in China and was introduced into the United States in the 1870s.

In the United States, commercial duck production relies solely on White Pekin ducks. A similar situation exists in much of Europe. They are ideally suited for meat production, producing excellent quality meat and reaching a market weight in 7 weeks. White Pekins are fairly good egg producers, averaging about 160 eggs per year. They are not good setters and they seldom raise a brood successfully. It is said that they should be treated gently to obtain maximum egg production.

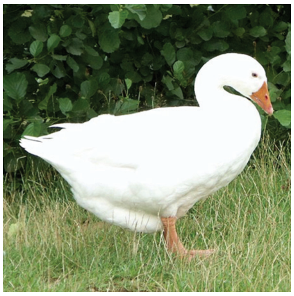
Examples of Duck Breeds

- **Aylesbury** ducks have white feathers, white skin, flesh-colored bills, and light-orange legs and feet. Eggs are tinted white. Adult drakes weigh 9 lb (4.2 kg) and adult females weigh 8 lb (3.6 kg). The breed originated in England. They have excellent meat quality and reach market weight in about 8 weeks. Egg production is generally below that of White Pekins, but records of 300 eggs per year have been reported. Aylesburys show some lack of interest in setting. Until recently, the Aylesbury was the major breed in the UK but has been surpassed by the Pekin.
- **Khaki Campbell** ducks are excellent layers, with 365 eggs per year by some hens reported, but they are valued tremendously for their meat. Young drakes and ducks weigh 3.5 to 4 lb (1.75 kg) at 2 months of age; adult drakes and ducks weigh 4.5 lb (2 kg). The breed originated in the United Kingdom from a cross of Fawn and White Runner, Rouen, and Mallard ducks. Males have brownish-bronze lower backs, tail coverts, heads, and necks, with the rest of their plumage being khaki. They have green bills and dark orange legs and toes. Females have seal-brown heads and necks, with the rest of the plumage being khaki. They have greenish-black bills and brown legs and toes. The White Campbell is derived from the Khaki, but has not become a popular egg producer. These ducks have orange bills and legs.
- **Indian Runner** ducks originated in the East Indies (present-day Indonesia), with its egg-producing capability developed in Western Europe. Three Indian Runner varieties are recognized: White, Penciled,

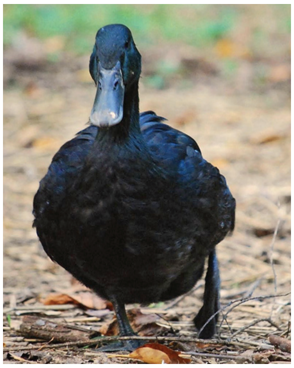
Appendix I Table 3 Breeds and varieties of ducks.

Class	Breed	Varieties
Bantam	Call	White, Snowy, Pastel, Gray, Chocolate, Buff, Butterscotch, Blue Bibbed, Blue Fawn
	East Indie	Black
	Mallard	Gray, Snowy
Heavy	Appleyard	Silver
	Aylesbury	White
	Pekin	White
	Rouen	Gray
	Muscovy*	Black, Blue, Chocolate, White
	Saxony	Only one variety
Light	Campbell	Khaki
	Magpie	Black & White, Blue & White
	Runner	Black, Buff, Chocolate, Cumberland Blue, Fawn & White, Gray, Penciled, White
	Welch Harlequin	Only one variety
Medium	Buff	Only one variety
	Cayuga	Black
	Crested	Black, White
	Swedish	Blue

*Recognized by biologists as a separate species.



A. Aylesbury



B. Cayuga

C. Indian Runner

D. Khaki Campbell drake

E. Khaki Campbell female

F. Orpington

G. Rouen

H. Pekin

Appendix I Figure 8 Breeds of ducks. (Sources: A. grassrootsgroundswell/Wikimedia Commons; B. Dana Kee/Wikimedia Commons; C. Nienetwiler/Wikimedia Commons; D. Steve Brace/Wikimedia Commons; E. Keith/Wikimedia Commons; F. Paul-Erwin Oswald/Wikimedia; G. Ian Griggs/Shutterstock; H. Martin Backert/Wikimedia Commons.)

and Fawn. All three varieties have orange to reddish-orange feet and shanks. Characteristically, the Runners stand erect. They weigh about the same as Khaki Campbells.

Examples of Geese Breeds

- **American Buff** geese have only fair economic qualities as a market goose, with a limited number raised for market. The color varies from dark buff on the back to a very light buff on the breast and from light buff to almost white on the underpart.
- **Chinese** geese grow rapidly, are attractive, and make a desirable medium-size market goose. It is very popular as an exhibition and ornamental breed. There are two standard varieties: Brown and White. It is smaller than other standard breeds and more "swanlike" in appearance. Both varieties mature early and are better layers than other breeds, usually averaging from 40 to 65 eggs per bird each year.
- **Emden** geese were one of the first breeds imported into the United States. This breed was known at first as Bremen, after the German city from which it was initially exported. The present name is after Emden (Germany), from which it was exported to England. The German name for the breed is "Emder Gans" or "Emdener Gans." The Emden is pure white and sprightly. It is much tighter feathered than the Toulouse and appears more erect. The Emden is a fairly

good layer (35–40 eggs per goose per year), but production depends on the breeding and selection of the flock. It is usually a better setter than the Toulouse and is one of the most popular breeds for marketing. It grows rapidly and matures early.

- **Pilgrim** geese are medium-sized and good for marketing. A unique feature of this breed is that males and females may be distinguished by color. In day-old goslings, the male is creamy white and the female gray. The adult male remains all white and has blue eyes; the adult female is gray and white and has dark hazel eyes.
- **Toulouse** geese are named after the city of Toulouse in southern France, which is noted for its geese. This breed has a broad, deep body and is loose-feathered, a characteristic that gives it a massive appearance. The plumage is dark gray on the back, gradually shading to light gray edged with white on the breast and to white on the abdomen. The eyes are dark brown or hazel, the bill pale orange, and the shanks and toes are deep reddish orange.

Appendix I Table 4 Breeds and varieties of geese.

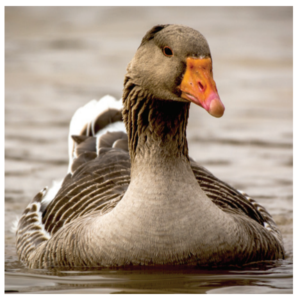
Class	Breed	Varieties
Heavy	African	Brown, White
	Emden	White
	Toulouse	Buff, Gray
Light	Canada	Eastern
	Chinese	Brown, White
Medium	Egyptian	Brown
	Tufted Roman	White
	American Buff	Buff
	Pilgrim	Sex-linked
	Pomeranian	Gray Saddleback, Buff Saddleback
	Sebastopol	White
	Steinbacher	Blue

A. Buff

B. Chinese

C. Emden

D. Pilgrim



E. Toulouse

Appendix I Figure 9 Breeds of geese. (Sources: A. Courtesy of Murray McMurray Hatchery; B. Oast House Archive/Wikimedia Commons; C. Bjoertvedt/Wikimedia Commons; D. Visharo/Shutterstock; E. Petra de witt/Shutterstock.)

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Appendix II

National Poultry Improvement Plan (United States)

The National Poultry Improvement Plan for chickens was established in 1935 under the USDA. The National Turkey Improvement Plan started in 1943. In 1970, the two were consolidated into the National Poultry Improvement Plan (NPIP). The plan's objective is to provide new technology through a cooperative state and federal program to effectively improve poultry health. The plan, developed by industry representatives and government officials, established standards for the evaluation of poultry breeding stock and hatcheries, for instance, freedom from hatchery disseminated diseases. Initially, the program aided in identifying the bacterial disease transmitted from the hen to the chick through the egg caused by the bacterium *Salmonella pullorum*. Today, breeders screen multiple diseases including pullorum disease (PD), Arizona infection (Arizonosis), fowl typhoid (FT), infectious bronchitis, Newcastle disease, *Mycoplasma gallisepticum* (MG), and *Salmonella enterica* serotype Enteritidis.

Information on the NPIP is available on the USDA Animal and Plant Health Inspection Service Website (http://www. aphis.usda.gov/vs/npip/). In 2002, the plan was amended to be consistent with developments in the poultry industry and with technological advances. The present National Poultry Improvement Laboratories are the following:

- Indiana Animal Disease Diagnostic Laboratory (Purdue University)
- Missouri Department of Agriculture Veterinary Diagnostic Laboratories
- California Animal Health and Food Safety Laboratory System
- Nebraska Veterinary Diagnostic Center
- Colorado State University Veterinary Diagnostic Laboratories
- North Carolina Veterinary Medicine Diagnostic Laboratories
- Cornell University Animal Health Diagnostic Center
- Ohio Animal Disease Diagnostic Laboratory
- University of Florida Diagnostic Laboratories
- Oregon State University Veterinary Diagnostic Laboratory
- Georgia Poultry Laboratory Network
- Penn State Animal Diagnostic Laboratory
- Iowa State Veterinary Diagnostic Laboratory
- Texas A&M Veterinary Medical Diagnostic Laboratory
- Kansas State University Veterinary Diagnostic Laboratory
- University of Connecticut Veterinary Diagnostic Laboratory
- Michigan State University Veterinary Diagnostic Laboratory
- University of Illinois Veterinary Diagnostic Laboratory
- University of Minnesota Veterinary Diagnostic Laboratory
- University of Missouri Veterinary Medical Diagnostic Laboratory
- Mississippi Veterinary Research and Diagnostic Laboratory System
- Washington State University Animal Disease Diagnostic Laboratory

Acceptance of the plan is optional with states and the industry. There is strong support for the plan by industry and government. The plan has been highly effective in controlling poultry diseases. By 1980, pullorum disease effectively ceased to exist in the United States. Of the 35.4 million chickens tested, only 0.000002% were reactors; and of the 3.2 million turkeys, there were no reactors. This is no small achievement; in 1920, when pullorum testing started, there were 11% pullorum reactors in chicken flocks.

Appendix III

Development of Chick Embryo

Appendix III Table 1 shows the Hamburger and Hamilton (1951) stages of development of the chick embryo.

Appendix III Table 1 The Hamilton-Hamburger stages of chick embryo development.

Stage	Time	Description
1	Before incubation	**Pre-streak** Embryonic shield (cells accumulating) possibly visible on blastoderm.
2	6–7 h	**Initial streak** or thickening (beginning of the primitive streak). Length is 0.3–0.5 mm (posterior border of pellucid area).
3	12–13 h	**Intermediate streak** A primitive streak from the posterior to middle of the pellucid area is seen.
4	18–19 h	**Definitive streak** The primitive streak is fully developed (length 1.9 mm). Primitive groove, primitive pit, and Hansen's node are present. Area pellucida now pear-shaped.
5	19–22 h	**Head process** or notochord is forming forward from anterior edge of Hensen's node. Stage 5 can be subdivided based on the length of the notochord. E.g., if the notochord is 0.3 mm long, then the stage is 5-0.3.
6	23–25 h	**Head fold** A fold in the blastoderm is seen anterior to the notochord. This is the anterior end of the embryo. No somites are present yet.
7	23–26 h	**1 (one) somite stage** One somite is clearly visible (2 are present). Neural folds can be seen in the head area.
8	26–29 h	**4 somites** Neural fold are meeting in the area of the mid-brain. There are blood islands in posterior blastoderm.
9	29–33 h	**7 somites** Optic vesicles formed. Heart is forming.
10	33–38 h	**10 somites** 3 brain vesicles (fore-, mid-, and hind-brain) visible. Heart is formed.

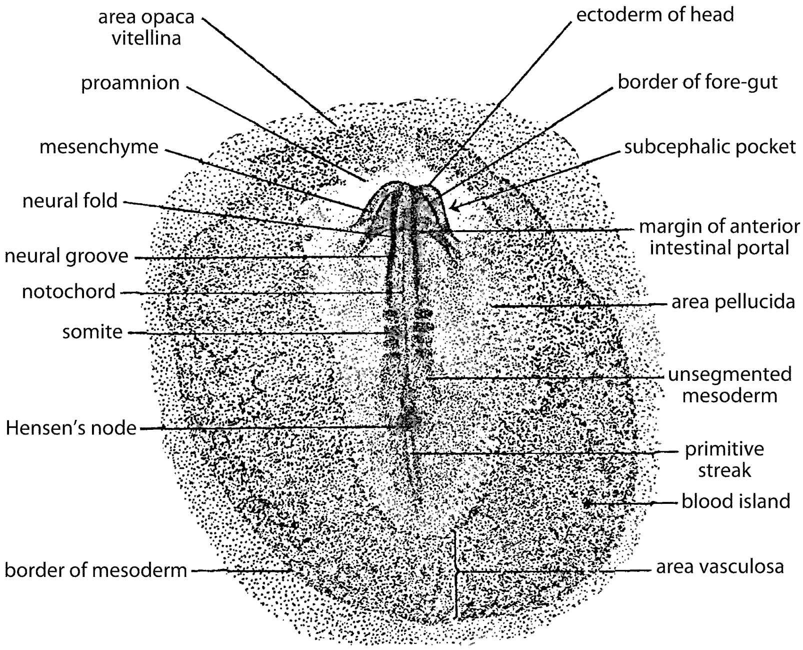
(continued)

Stage	Time	Description
11	40–45 h	**13 somites** Cranial flexure beginning. Optic vesicles are constricted at their bases. Heart bent to the right.
12	45–49 h	**16 somites** Head beginning to turn to the left. Optic stalk is formed. Auditory pit is formed. Heart is becoming S-shaped. Head fold of amnion covers forebrain.
13	48–52 h	**19 somites** Head is turned to the left. Enlargement of telencephalon. Head fold of amnion covers forebrain, midbrain and part of hind brain.
14	50–53 h	**22 somites**—flexures and rotations. Rathke's pouch (leading to pituitary gland) is formed. Auditory pit opening is constricted. Amnion covers the brain and somites up to about 7–10.
15	50–55 h	**24–27 somites** Lateral body folds have extended to somites 15–17 (level of wings). Limb primordia flat. Amnion covers brain and somites to about 7–14.
16	51–56 h	**26–28 somites** Lateral body folds have extended to somites 17–20 (level between wings and legs). Wing has lifted off blastoderm. Leg primordia flat. Amnion covers brain and somites to about 7–14.
17	52–64 h	**29–32 somites** Lateral body folds have been extended fully around body. Wing and leg buds have been lifted off the blastoderm. Variability in amnion and no allantois yet.
18	65–69 h	**30–36 somites** Limb buds are larger. Allantois pocket formed.
19	68–72 h	**37–40 somites** (extending into tail). Limb buds are larger, with wing buds smaller than leg buds. Eyes are not pigmented. Allantois still small.
20	70–72 h	**40–43 somites** (into tail). Limb buds are larger with ratio of legs to wings greater. Eye starting to get pigment. Allantois growing.
21	3.5 d	**43–44 somites** to tip of tail (all somites have formed). Limbs seen. Eye pigmentation is still faint. Allantois growing.
22	3.5 d	Limb buds are elongated. Eye pigmentation is distinct. Allantois extends to head.
23	3.5–4 d	Elongation of limb buds has been continued. Contour from hindbrain to tail is a curve.

Stage	Time	Description
24	4 d	Limbs—the toe plate is formed.
25	4.5 d	Limbs—knee and elbow joints are formed and third toe indicated.
26	4.5–5 d	Limbs—three toes visible.
27	5 d	Limbs—three toes distinct. Beak may be seen.
28	5.5 d	Limbs—four toes distinct. Beak clearly seen.
29	6 d	Limbs developing with wing bent at elbow and rudiment of 5th toe. Beak is larger.
30	6.5 d	Limbs developing (e.g., wing bent at elbow and knee, 3 elements of limbs have been formed). Two dorsal rows of feather germs and 3 rows in legs. Beak is larger and egg tooth formed.
31	7 d	Limbs developing. Web between first and second digits. Fifth toe can still be seen. Feather germs are developing.
32	7.5 d	Limbs developing. Four toes have lengthened. Fifth toe gone. 11 rows of feather germs on dorsal surface of legs.
33	7.5–8 d	All digits and toes lengthened.
34	8 d	Second digit and third toe clearly visible. Nictitating membrane (eyelid) has developed.
35	8–9 d	Nictitating membrane easily visible. Eyelids begin to grow over cornea. Beaks lengthening. Webs between digits and toes lost and phalanges visible.
36	10 d	Lower eyelid reaches cornea. Multiple feathers with 9–10 rows of feather germs between upper eye lid and dorsal midline. Beak length is 2.5 mm. Length of third toe is 5.4 mm.
37	11 d	Lower eyelid covers 1/3–1/2 of cornea. Upper eyelid reaches dorsal cornea. Feather germs: tracts more numerous. Beak is 3 mm. Length of third toe is 7.4 mm.
38	12 d	Lower eyelid covers 2/3–3/4 of cornea. 2–3 rows of feathers germs at edge of lower eyelid. Beak is 3.1 mm. Length of third toe is 8.4 mm.
39	13 d	Opening of eyelid is reduced to thin crescent. 4–5 rows of feathers germs at edge of lower eyelid. Beak is 3.5 mm. Length of third toe is 9.8 mm.
40	14 d	Beak: 4.0 mm. Third toe: 12.7 mm.
41	15 d	Beak: 4.5 mm. Third toe: 14.9 mm.
42	16 d	Beak: 4.8 mm. Third toe: 16.7 mm.
43	17 d	Beak: 5.0 mm. Third toe: 18.6 mm.

(continued)

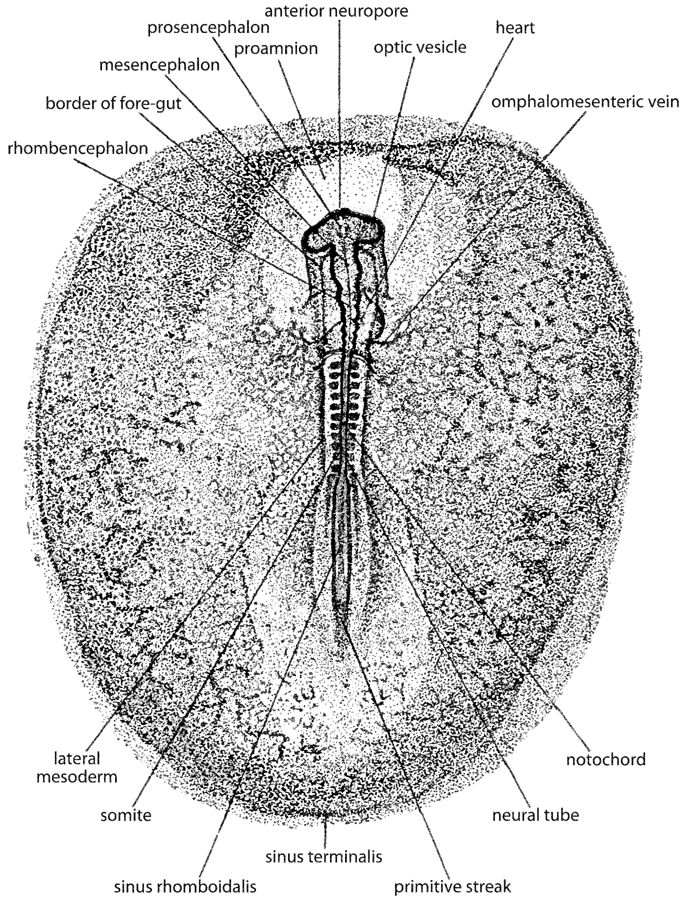
Stage	Time	Description
44	18 d	Beak: 5.7 mm. Third toe: 20.4 mm.
45	19–20 d	Enclosure of yolk sac in body cavity is half completed. Reduced blood in the chorioallantoic membrane. Little change in beak and toe length.
46	20–21 d	Chick immediately after hatching.

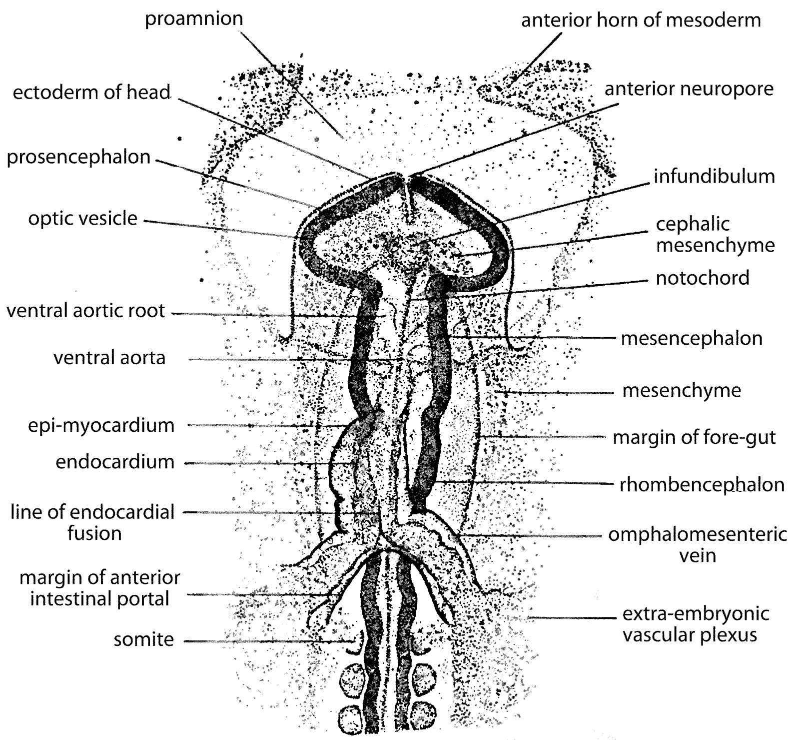


Appendix III Figure 1 Hamilton-Hamburger stage 8; 4 somite stage (1 day of incubation).

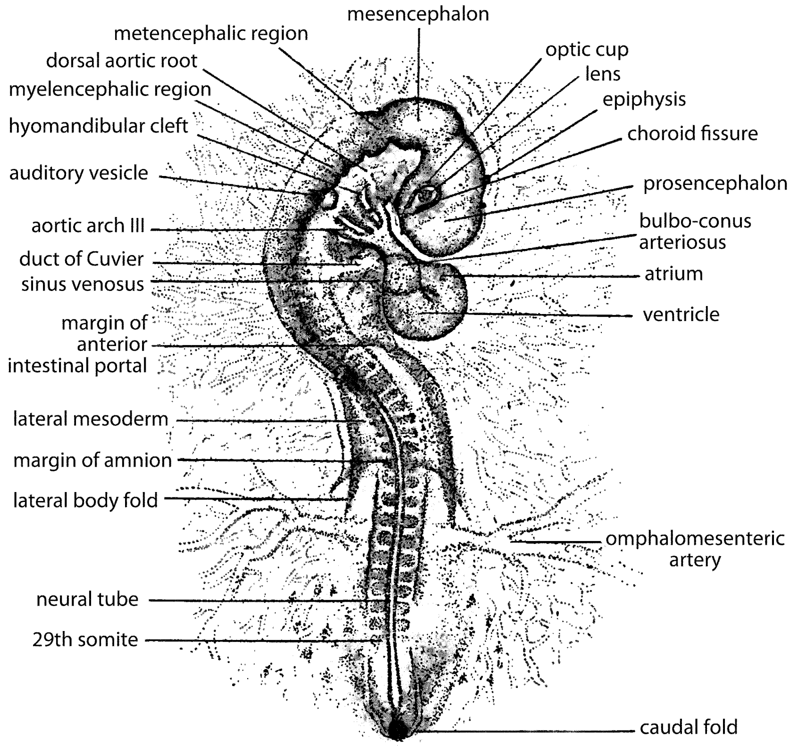
Note: All five figures are from B. M. Patten's *The Early Embryology of the Chick* (1920). There is a more recent series of stages of development of the chick embryo (Eyal-Giladi and Kochav, 1976). This includes the stages when the egg is in the hen.

Appendix III Figure 2 Hamilton-Hamburger stage 10; 12 somites (1.37 days of incubation).

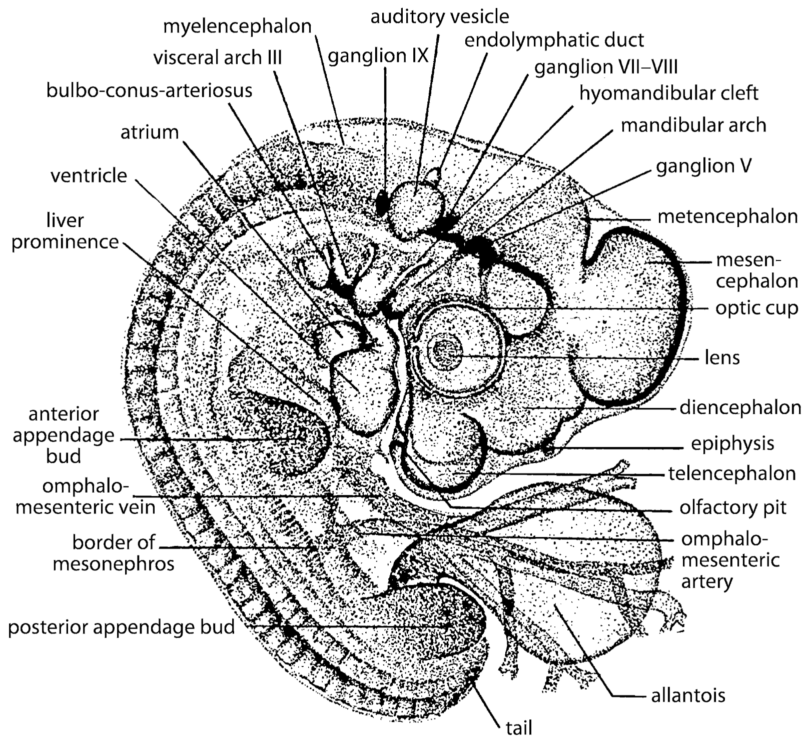




Appendix III Figure 3 Hamilton-Hamburger stage 10; 9 somite stage, showing early development of the head and chest.



Appendix III Figure 4 Hamilton-Hamburger stage 14 (2.5 days of incubation).



Appendix III Figure 5 Hamilton-Hamburger stage 20; 41 somite stage (4 days of incubation).

Index

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