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Edited by Joy A. Mench

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Joy A. Mench

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Preface

Animal welfare began to emerge as a scientific discipline in the 1960s, and there is now a large body of published research addressing a range of fundamental and applied topics. However, the field is currently in a stage of transition, with an increasing emphasis on translating the knowledge that has been gained into “real world” improvements. This is necessitating new and ever more sophisticated research approaches, including the collection of more complex data with an increasing focus on solutions, the development and use of new research methodologies and technologies, and the integration of information across different disciplines. It also requires enhancing communication and collaboration among diverse stakeholders, as well as developing science-based approaches for setting “best practice” standards and onsite welfare assessments to help ensure public confidence.

The five books in this series provide overviews of key scientific approaches to assessing and improving the welfare of farm animals and address how that science can be translated into practice. The books are not meant to provide a comprehensive overview, but instead focus on selected “hot topics” and emerging issues for cattle, pigs, poultry, and sheep (as well as the overarching issue of linking animal welfare science and practice). Advances and challenges in these areas are presented in each book in the form of an integrated collection of focused review chapters written by top experts in the field. The emphasis is not just on discussing problems, but on identifying methods for mitigating those problems and the knowledge gaps that remain to be filled.

Although the topics reviewed in the cattle, pig, poultry, and sheep books are tailored to those most important for the particular species, all of the books include an overview of production systems and discussion of the most pressing animal welfare challenges and important advances associated with those systems from the perspectives of normal and abnormal behavior, animal health, and pain management. Emphasis is placed on both management and genetic approaches to improving welfare, as well as on emerging scientific tools for investigating questions about the welfare of that species. As relevant, the books also include reviews on human−animal interactions and transport and/or slaughter. Finally, practical tools for in situ (on the farm, during transport, or at the slaughter facility) assessment of welfare are presented. The reviews in the overview volume focus on animal welfare in the context of agricultural sustainability, and also address how science can be translated into practice taking into account ethical views, social developments, and the emergence of global standards.

The topics covered by these books are highly relevant to stakeholders interested in the current and future developments of farm animal welfare policies, including farmers, food industry, retailers, and policy makers as well as researchers and veterinary practitioners. The editors hope that they serve not only to help improve farm animal welfare but also to encourage discussion about future directions and priorities in the field.

Joy Mench
Series Editor

Introduction: Topical issues in poultry welfare

Global poultry production is massive in scale, with tens of billions of chickens, turkeys, ducks, and other poultry species raised every year for meat and egg production. While most poultry are raised in commercial systems, there is also a great deal of village or backyard production, mainly in developing countries but also increasingly in developed countries. The last 60 years has seen an impressive research effort devoted toward developing and validating methodologies for poultry welfare assessment, identifying welfare problems in various poultry production systems, and evaluating housing modifications, management methods, and technologies to improve welfare from hatch to slaughter. Reviewing this large body of research is well beyond the scope of this book—instead, the goal is to discuss some of the "hot topics" in poultry welfare by providing an overview of existing knowledge and identifying the constraints and benefits associated with applying that knowledge in the production environment, as well as pointing out knowledge gaps that need to be addressed in future research efforts.

The book opens with an overview chapter by Darrin Karcher and myself describing (in words and pictures) *commercial production systems for poultry and the main animal welfare challenges* in each of those systems. Systems for the different meat birds (broiler chickens, ducks, and turkeys) are similar to one another in configuration and management, while those for laying hens are quite diverse, ranging from conventional or enriched cages, to single- or multi-tier noncage with or without outdoor access, to fully free-range (pasture-based). A variety of welfare challenges have been identified in all systems and for all species and these are briefly described, with a focus on health and behavior. We note that our summary represents a "point in time," since poultry production systems are continuously evolving to meet changing consumer and customer demands.

In Part II of the book, several key areas related to management of poultry during early life stages and at slaughter are addressed. Karen Schwean-Lardner evaluates *the effects of hatchery practices on the welfare of poultry*. Her review covers incubation conditions and addresses the question of when embryos are sufficiently developed to suffer. It also discusses posthatch aspects of welfare, such as handling, beak-trimming, and transport. Karen's review demonstrates that what happens to embryos and chicks/poults at the hatchery matters not just for their immediate welfare but later in life, indicating that this aspect of poultry production would benefit from further research and research application. Tina Widowski and Stephanie Torrey discuss another under-researched topic, how we can *rear young birds for* *adaptability* to later management conditions, focusing on preparing pullets for layer housing systems, early feeding of chickens and turkeys, and rearing of chickens and turkeys for social adaptability. They point out how influential early life experiences can be in reducing fearfulness and improving bone health and locomotion in laying hens and aggression, stereotypic behavior, and mortality in meat birds. The next two chapters focus on poultry slaughter methods. Bert Lambooij and Vincent Hindle discuss the welfare and meat quality aspects of *electrical stunning of poultry*. They describe the general principles behind electrical stunning, and then discuss the humane considerations surrounding restraint and stunning methods. They conclude that the disadvantages associated with conventional methods of restraint (shackling) and electrical stunning are such that the search for alternative electrical stunning technologies needs to continue. Yvonne Vizzier Thaxton reviews *gas and low atmospheric pressure stunning (LAPS)* (together called "controlled atmosphere stunning") methods as alternatives to electrical stunning. She describes the welfare advantages and disadvantages of each, with a major advantage being that all of these methods eliminate the need for live birds to be shackled. She also points to the improvements in meat quality associated with controlled atmosphere stunning as compared to electrical stunning, an economic benefit for producers but one that may still be outweighed by the current cost of installing gas or LAPS systems.

Part III of the Book deals with *welfare assessment on the farm*. Andy Butterworth describes how using outcome-based measures of welfare, which typically focus on measuring the behavior, health, or physical condition of the animals, are useful for gaining a picture of welfare status with a focus on the group (in this case, a producer's flock). He describes three poultry welfare assessment schemes to illustrate how outcome-based measures are chosen, measured on farm, and scored. He also discusses the use of outcome-based measures by producers, retailers, and veterinarians as a welfare improvement tool, but cautions that more work is needed to ensure that these measures are of real value to farmers and consumers. Given the large flock sizes characteristic of commercial production, it is sometimes difficult to remember that each flock is composed of individual birds, each with their own welfare needs. Jose Linares, Suzanne Dougherty, and Suzanne Millman provide a *focus on the individual* bird, reviewing the biology underlying the effects of pain and illness on bird behavior and advising how this knowledge can be used to recognize sick or injured birds in flocks. They also describe methods for on-farm euthanasia of sick or injured individuals that cannot be treated with regard to their humane and practical considerations.

In Part IV, several areas of continuing challenge are addressed. While there has been significant research in each of these areas, there are still major gaps in our knowledge that limit our ability to make rapid practical advances. Mike Toscano reviews an area that is considered to be one of the most important current welfare issues in commercial laying hen production, *skeletal problems*. He first discusses the factors that influence bone development, and then provides an overview of the known or suspected causes of keel bone abnormalities and long bone fractures. He concludes that assuming that skeletal problems are due only to high rates of egg production, with its associated need for calcium for eggshell formation, is too simplistic, and that environmental, nutritional, and genetic factors will need to be more thoroughly understood before these problems can be reduced. Beak-trimming of poultry to reduce injury due to feather pecking and cannibalism (tissue pecking) has been a welfare concern for many years because of its potential to cause pain, and there are growing calls in Europe to ban this procedure. Christine Nicol asks: *can we really stop beak trimming*? She discusses the causes of outbreaks of feather and tissue pecking in laying hen flocks, and reviews the potential for management changes and genetic selection to reduce or eliminate these problems. While she believes that eliminating beak-trimming in the short term will be difficult, especially in cage-free systems, she is also optimistic that taking a holistic approach that involves on-farm testing and re-testing of various management strategies will be beneficial in continuing to reduce problems with injurious pecking over time.

Increasingly, farm animal welfare is viewed as just one component of the overall sustainability of animal agriculture. But this raises the complex issue of deciding how to balance concerns for animal welfare against other elements of sustainability. Bas Rodenburg and I discuss what is known, and what is not known, about the *sustainability of laying hen housing systems* in our chapter. We review the literature on the environmental, worker health, and safety, animal welfare, egg safety and quality, and economics in the different hen production systems currently in use globally. Because the sustainability risks vary in each system, there is no "best system" to address all sustainability concerns, particularly given the role that public values and perceptions will play in determining the acceptability of different housing systems. Our recommendation is that future efforts should be targeted toward risk mitigation, for example by focusing on reducing a problem like hen mortality which has negative implications for all aspects of sustainability.

Marian Dawkins tackles the thorny problem of *how we judge how much space poultry need*. It seems to be a given when animal welfare guidelines are written that there must be some numerical requirement for minimum space allowance per bird, but where do those numbers come from? Marian describes how health and behavior measures have been used in an attempt to quantify space requirements. She concludes that discrepancies between studies are due in part to methodological differences, but that the real issue is that space is so complex that we should think about it in new ways rather than trying to find a single "right" number that will achieve welfare objectives. One important element of space use is related to social interactions among flock members, a topic addressed by Inma Estevez in her chapter on *understanding social behavior for better flock management*. She describes the factors that influence flock cohesion, and points out that, although studies have shown that chickens are actually highly flexible and adaptive in their social behavior, changes in the appearance of birds in a flock or inadequate resource provision can still trigger aggression. She then sets out some management measures than can be taken to reduce these problems in production and breeding flocks.

Finally in this part of the book, Marisa Erasmus reviews *welfare issues in turkey production*. Because chickens make up by far the majority of poultry production worldwide, until recently much less attention has been focused on welfare issues for less common species like turkeys and ducks. Marisa provides an overview of the extent and potential causes of welfare problems in turkey flocks, including injurious pecking, footpad dermatitis, leg and skeletal abnormalities, death and injury during transport to the slaughter plant, and stress associated with feed restriction of turkey breeders. She highlights needed research, including to further develop resource (e.g., space) and outcome-based measures to improve turkey welfare on-farm and to evaluate management practices to maintain turkey health in the light of increasing demands for organic and antibiotic-free turkey meat.

In Part V, a number of emerging issues are discussed. Brad Mullins and Amy Murillo cast their eyes on *the future of poultry pest management*, reviewing the problems associated with finding effective alternative methods of pest control in a climate of increasing public wariness about the use of traditional pesticides because of their potential to contaminate food and the environment. After discussing the poultry pest complex and the risks for infestation in different housing systems, they describe some potential nonchemical approaches to parasite control, although they note that many of these are still at an early stage of development. They conclude that more emphasis needs to be placed on biosecurity to reduce infestation potential and on integrated strategies for pest management to reduce the need for chemical control. Yin Wang, Perot Saelao, Khin Mon, Tae-Hyun Kim, Terra Kelly, and Huaijun Zhou address the potential for improving poultry's *responses to environmental stressors using genetic approaches* focusing on heat stress and resistance to diseases like Avian Influenza and Newcastle disease, as well as the foodborne pathogen *Salmonella*. They describe how recent technical developments in genetic and genomics are helping to understand the mechanisms underlying genetic control of responses to these stressors, and how this information can be utilized to improve poultry health and welfare by identifying avenues for genetic enhancement. This topic is particularly important given the prospects of global warming and the projected increase in poultry production in the developing world where Newcastle disease is a major source of poultry mortality.

The topic of *backyard flock production* is then taken up by Richard Blatchford. He outlines the welfare concerns in backyard production related to housing and management, health and biosecurity, and behavior problems. He also describes the challenges backyard owners face with respect to regulations and a lack of access to information and resources and food safety, and calls for increased outreach by experts to this growing sector of poultry production. Finally, Dorothy McKeegan deals with the difficult issue of *mass depopulation*, a topic that has recently come to the fore because of the need to euthanize large numbers of birds during the recent outbreaks of Avian Influenza to prevent suffering and limit disease spread. She describes the strengths and weaknesses in terms of welfare implications, biosecurity risks, flexibility, technical complexity, and cost of the methods that are currently being used, or proposed for use, for mass depopulation of poultry flocks. She also indicates that methods are currently available that can protect flock welfare without compromising disease control or public health protection, while recognizing that a number of other factors may drive the choice of method in particular situations.

I hope that the chapters in this book will be thought-provoking for the various stakeholders who are interested in poultry welfare, and also provide useful information about the techniques and technologies that are currently available to identify and reduce welfare problems. I also hope that they can help in focusing future research efforts and practical implementation strategies by identifying areas where more effort is needed.

Joy Mench

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Part I

Introduction

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Overview of commercial poultry production systems and their main welfare challenges

1

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1.1 Introduction

Commercial poultry production practices have changed dramatically since the 1950s. Most commercial poultry are now raised entirely indoors, in environmentally or semi-environmentally controlled buildings. They are managed to maximize production, for example by feeding diets that are formulated for their nutritional needs at various stages of the rearing or egg-laying cycle and by providing controlled photoperiods and light intensities to stimulate growth or egg laying. A major source of change has been the intense genetic selection for either growth or egg laying, leading to the development of two different types of poultry—meat birds and table-egg layers—which are managed by two separate sectors of the poultry industry.

As a result of these factors as well as advances such as better prevention and control of disease via vaccines and antibiotics, the poultry industry has grown significantly over the last few decades, with the consumption of both poultry meat and eggs increasing globally, an increase that is predicted to continue, particularly in developing countries (NRC, 2015). Although many different species of poultry are grown around the world for meat and eggs, the three primary species produced commercially are chickens (for meat and table eggs), ducks (mainly Pekin ducks for meat), and turkeys (for meat).

As production has grown and intensified, so too have concerns about animal welfare. As early as 1965, the influential U.K. Brambell Committee "*Report of the Technical Committee to Enquire into the Welfare of Animals Kept under Intensive Livestock Husbandry Systems*" identified a number of potential welfare issues in commercial poultry production, including beak trimming (which they suggested might cause pain), the restriction of space and behavior in conventional cages for hens, risks of disease and cannibalism in loose housing systems for hens, the use of dim lighting for both meat chickens and laying hens, high stocking densities for broiler chickens and turkeys, and the potential for mechanical failure in automated housing systems (Brambell, 1965). Most of these concerns persist, and others have emerged as commercial production systems have evolved and public interest in animal welfare has continued to intensify, particularly in developed countries.

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In this chapter we describe the main systems used for rearing commercial meat and egg-laying chickens, Pekin ducks, and turkeys, and give a short overview of the key welfare issues. The focus is mainly on production systems in the United States, but similar systems are used in many other countries although they may be managed somewhat differently due to local differences in legislation, standards, availability or cost of resources (for example litter or feedstuffs), or markets. We note that, in the United States, there are no federal laws that regulate the animal welfare aspects of housing systems or production practices for poultry aside from the provisions included in the standards of the National Organic Program. Instead many producers follow voluntary animal welfare standards established by their industry trade organizations, and/or those of independent (third-party) certifiers (e.g., retailers, animal welfare labeling programs). Although the main focus of this chapter is on rearing and production systems for meat and egg-laying poultry, we briefly address some of the welfare concerns associated with breeding, hatcheries, and loading and transport. Detailed information about the welfare aspects of slaughter, euthanasia, and mass depopulation of poultry (when there is a serious disease outbreak, for example) can be found elsewhere in this volume (Lambooij and Hindle, Chapter 4; Linares et al., Chapter 7; McKeegan, Chapter 17; Vizzier-Thaxton, Chapter 5).

1.2 Meat birds

1.2.1 General aspects of housing and management

The rearing systems for broilers, turkeys, and ducks are quite similar. In general, meat bird production systems involve rearing birds indoors on a litter floor. The litter is typically wood shavings-based but straw, sand, rice hulls, and other materials may be used. Houses average 20,000 ft^2 (1858.1 m^2) in area but stocking density varies depending on the type of meat bird being raised. The birds are placed in the house on the day of hatch (started) and provided with supplementary heat during the brooding phase, which may involve confining them to a portion of the house until they are better able to regulate their own body temperature. Automated drinkers and auger feed lines are used to deliver feed and water. Diets are phase fed, which allows for the requirements of the growing birds to be met during the different production phases.

Houses may have either tunnel ventilation or natural ventilation; in the United States, ventilation type depends on geographic location of the farm. Tunnel ventilation pulls the air through the house using inlets and exhaust fans while natural ventilation utilizes open-sided houses with curtains to control the amount of air flow. Lighting programs typically provide 23:1 light:dark for the first 7 days and then 20:4 for the remainder of the production period. However, there are many different kinds of lighting programs and the way the light is provided (e.g., lighting type, intensity, and long or intermittent blocks of light) can vary from one farm to another, and according to whether producers are following particular standards. Daily care entails walking the house at least once per day to collect mortality, identify health issues

(Linares et al., Chapter 7), verify that feed, water lines, and other equipment (e.g., ventilation) are working appropriately, and check litter condition.

After the birds are sent to the processing plant, the producer prepares the house for another flock of birds. At a minimum this requires cleaning the feed and water lines, as well as removing large aggregates of litter and redistributing and conditioning the remaining litter in the house. For biosecurity reasons related to disease prevention, producers usually wait for 10 to 21 days before placing a new flock in the house. Some countries and certification programs have more stringent requirements for house preparation, for example, requirements to remove and replace all litter or to follow particular cleaning and disinfection protocols between flocks.

Below, we present an overview of the intensive systems that are the ones most commonly used for the commercial production of meat chickens, turkeys, and ducks. However, there is a small but growing segment of the industry in developed countries that raises meat birds in systems that range from semi-intensive to extensive. These include systems that provide the birds with outdoor access once they are past the brooding period (free-range) and systems where the birds are raised primarily outdoors (pasture-based systems or pond-based systems for ducks). Either free-range or pastured systems can be used for organic production, as long as they meet legal requirements (e.g., related to provision of organic feedstuffs and restrictions on the use of particular compounds for the prevention or treatment of disease). These systems tend to be quite variable in terms of their management and configuration, and producers may use atypical breeds, like Heritage breeds, that are better suited for outdoor rearing than typical commercial breeds or strains. Because of their variability, we will not attempt to describe these systems here, although some mention is made later about welfare concerns related to outdoor access for both meat and egg-laying birds, as well as organic production.

1.2.2 Broilers (meat chickens)

The USDA Agricultural Marketing Service defines four classes of meat chickens (Cornish game hen, Rock Cornish fryer or roaster, broiler or fryer, roaster) based on age, extent of keel bone (breastbone) calcification, and genetic stock (AMS, 2002). The industry, however, defines classes based on the size of the bird marketed ("small" to "big"), with days to market varying between 33 and 64 for the different sizes of birds. The difference in days to market is based on the final disposition of the carcass, i.e., as a whole bird, parts, or for the fast food or further processed product markets. Female and male chicks are usually raised together (referred to as straight-run rearing), but may sometimes be raised in separate houses (sex-separate). Fig. 1.1 shows a typical commercial broiler house during both the early and late rearing stages.

In the United States, the standards of the National Chicken Council (NCC), which is the trade organization for broiler producers, recommend stocking densities varying from 6.5 to 9.0 pounds of live weight per 1 ft^2 (929 cm^2) of house floor area (31.7−43.9 kg/m^2) depending upon the desired market weight of the birds (NCC, 2017), whereas the European Union (EU) standards specify a range from 6.8

Figure 1.1 (A) Broiler chicks in a conventional house with alternating feed and water lines. Notice the plastic curtain in the background dividing the house to create a brooding area initially. (B) Broiler chickens close to market age in a tunnel ventilated production house.

to 8.0 lbs/ft^2 (33−39 kg/m^2) depending not only on bird size but on other aspects of management related to house air quality and thermal control (CEC, 2007). Daytime light intensities after the first week of the rearing period are typically kept very low, often less than 5 lx in the United States, although higher intensities are required in some countries (e.g., in the EU, where a minimum of 20 lx is required over 80% of the house throughout most of the production period) and for some certification programs. Drinking water is typically provided via nipple drinkers to help maintain the litter in dry condition.

When the birds are ready for market, the feed and water lines are hoisted to the ceiling, eliminating obstacles for the catch crew. Broilers can be caught by hand or by machine (e.g., chicken harvester or catching machine). With hand catching, the catch crew enters the broiler house and corrals the birds into a catching area.

Transport containers are brought into the house and the crew hand-catches the birds and places them into the transport coops (crates). When each bank of coops is filled, it is placed onto the transport truck. If a catching machine is used, an individual controls the machine as it moves through the house. The machine uses a system of belts to move the broilers from the floor of the house to the transport coops. Each individual bird is weighed and when the desired total bird weight is reached for a particular coop, the belt is moved to the next coop. The number of broilers placed into each coop is dictated by bird size, ambient temperature during transport, and any third-party certifications that are being followed.

1.2.3 Turkeys

The USDA Agricultural Marketing Service defines two classes of meat turkeys (fryer-roaster and young) based on age and extent of keel bone (breastbone) calcification (AMS, 2002). The commercial industry classifies turkeys as heavy or light toms or hens. It takes 84 to 140 days for turkeys to reach target weights, depending on the sex of the young turkey (poult) and the time of year. The decision to produce a heavy or light bird depends on whether the turkey will be marketed as a whole bird or as further processed products. Toms and hens (males and females) are reared separately. Unlike the other meat birds, poults are brooded in a building that is separate from the production house, into which they are moved at around 6 weeks of age (Fig. 1.2). The brooder house is cleaned and disinfected between each group of poults.

In the United States, stocking densities vary by third-party certification groups (Erasmus, 2017). Currently, while the National Turkey Federation (NTF), which is the trade organization for US turkey producers, does have turkey welfare standards (NTF, 2016), these do not include stocking density recommendations. Rather, densities are determined by other aspects of management related to house air quality and thermal control. Lighting programs and intensities are typically kept low, but beyond the requirement for a dark period (NTF, 2016) the actual lighting program (photoperiod and intensity) is determined by the individual companies. Drinking water is usually provided via bell waterers; however, some houses have nipple drinkers. The feeders consist of round feed pans that are filled via an auger system. Feeders and waterers are adjusted to the level of the birds' back to eliminate feed and water wastage.

When the turkeys are ready for market, the feed and water lines are raised to the ceiling prior to loading the birds onto the truck. Turkeys are usually loaded by herding rather than being caught by hand. The turkeys are walked toward the loading area, where they are placed onto a conveyor system to move them out of the house and into the coop area on the transport truck. Several individuals slowly walk the birds toward the conveyor, ensuring a steady flow of turkeys onto the conveyor but not creating excitement which could cause the turkeys to pile at the conveyor system. At the top of the loader, workers "drive" the conveyor controlling the speed at which the turkeys are moved to the top of the conveyor and counting the number of birds placed into each transport coop.

Figure 1.2 (A) Turkey poults in a tunnel ventilated house with alternating feed and water lines. (B) Turkey toms close to market age in a naturally ventilated house.
Source: Photograph of toms courtesy of Butterball LLC.

1.2.4 Pekin ducks

Meat ducks are defined by USDA-AMS as two classes (broiler or fryer and roaster), with duck age and calcification of the bill and windpipe determining the classification (AMS, 2002). However, ducks are sent to market based on desired weight and disposition of the processed carcass (whole duck, parts, or further processed products). This results in ducks being processed between 38 and 45 days of age. We

Figure 1.3 Ducklings housed on raised plastic flooring with alternating feeders and water lines.

focus on Pekin ducks here because they are the main type of duck produced in the United States (and globally), but other types of ducks, e.g., Muscovy or Moulard (mule) ducks, may be produced for specific markets.

Pekin ducks are reared as mixed-sex flocks in three different types of rearing systems: litter floors, raised plastic flooring, or a combination of the two. Irrespectively, the ducklings are brooded in a smaller area of the production house where a higher temperature can be achieved for brooding. When the ducklings are around 3 weeks of age, the brooder area is opened up providing more area of the house for the ducklings to use. As they continue to grow, the entire house becomes accessible to them (Fig. 1.3). Currently, there is no trade organization in the United States that has standards for Pekin ducks.

When it is time to send the ducks to the processing plant, the house equipment is lifted to make loading easier. As for turkeys, Pekin ducks are herded rather than hand-caught. The loading crew walks the ducks to the truck loading ramp. The ducks are counted as they are walked onto the ramp to ensure that the proper number of ducks is placed in each pen on the transport truck. Once a level of the truck is filled with ducks, a floor is lowered down to begin another tier of pens, with approximately six tiers on a truck.

1.3 Egg-laying chickens

Egg-laying hens have been selected to maximize egg production and egg quality traits; commercial strains lay about 250 to 310 eggs per year. Genetically speaking, there are two types of laying hens: white egg layers and brown egg layers. The hen genetic stock kept by a particular producer varies by region or location within the world, but is strongly driven by consumer preference for eggshell color or type of egg being produced, i.e., a shell egg or an egg for the liquid egg market. In some areas of the United States, for example, brown eggs can be sold for a premium while in other locations they cannot. There are a multitude of housing systems in use, spanning the extensive to intensive spectrum. An expanded section on each type of housing system can be found below. Each of the different housing systems requires a different level of management skill to ensure high levels of productivity while striving to optimize laying hen welfare within that system.

1.3.1 Pullets

Female chicks that have not laid an egg are referred to as pullets. The term pullet is used until approximately 18 weeks of age, at which point egg production begins. Pullets are reared in two major types of housing systems—brooding cages or litter brooding—or a hybrid of these (referred to in the United States as non-cage aviary pullet rearing). These rearing systems are shown in Fig. 1.4. For cage brooding, at around 4 weeks of age, half of the chicks are moved from their initial cage to another cage to provide them with additional room and access to resources until

Figure 1.4 Pullet rearing systems. (A) White layer pullets in a brooding cage. The water line (unseen) is inside the cage while the feeder is located externally. (B) Brown layer pullets in a cage-free pullet rearing facility. The feeder and water line are both internal providing a perch for the pullets. The chicks will be provided access to the litter area at approximately 6 weeks of age. (C) Brown layer pullets in a cage-free pullet rearing facility. The brooding cages have been opened, providing the pullets with access to the litter area. Ramps and perches are installed to allow pullets to more easily navigate the house.

they are moved into the hen house at approximately 17 weeks of age. In a litter brooding environment, all chicks are placed on a littered floor, generally confined to an area of the house that can be adequately heated to help them maintain their body temperature. As they grow, the usable area of the house is expanded to provide additional space and resources. Finally, in a hybrid system, chicks are initially placed in a brooding cage, but at around 6 weeks of age are provided access to the floor. Both litter brooding and hybrid brooding allow the pullets to familiarize themselves with items such as perches, ramps, and/or ladders that are provided on the litter to help them navigate a complex environment, such as an aviary, in which they will be housed as mature layers.

Pullets are fed a diet that is nutritionally formulated based on the primary breeder's management guide. Daily care entails walking through the pullet house identifying mortality and birds that appear unhealthy, as well as checking feed and water lines to ensure there are no malfunctions. A vaccination program developed with a veterinarian that entails both spray vaccines and injections is used throughout the first 13 weeks of life. A typical pullet lighting schedule starts with 24 hours of light, decreasing to 22 hours of light by 7 days of age between 5 and 10 lx, with an illumination level between 5 and 10 lx. Producers then continue to decrease the photoperiod, achieving 8–10 hours of light by 7 weeks of age. Pullets are then maintained on this photoperiod until they are moved into the hen house, at approximately 18 weeks of age.

1.3.2 Laying hens—General aspects of production and management

A laying farm may be "in-line" or "off-line" with respect to how the eggs are handled. A farm where the eggs are produced in the house, placed on egg flats, stored in a cooler, and moved to a separate egg processing facility is considered off-line. If the eggs produced at the farm travel on conveyor belts to a central egg processing plant located at that farm, then it is considered to be in-line. At an in-line farm, the feed mill, production houses, and egg processing plant are all at the same location. The feed mill is connected via an auger system to each house and delivers unique diets to the external feed bins located at that house. An off-line farm has a central feed mill and the diets are trucked to each farm. An in-line or off-line laying farm may have either one house or multiple houses. Houses vary in size, but a single house typically contains 50,000–200,000 hens. Each house contains hens of the same age, and houses are staggered in terms of hen age to ensure a consistent egg supply while allowing for an all-in-all-out biosecurity approach in each house. A laying farm may continue to grow over time by increasing the number of houses, which increases the number of eggs produced at a single location.

Similar to meat birds, important aspects of laying hen management are nutrition, lighting, and daily care. Laying hen nutritional needs are well established from research conducted over the past 75 years. Laying hens are fed phase diets that are formulated to meet the requirements of the hen's productive status throughout the lay cycle. Typically, around 6 different diets are fed from 17 weeks of age to the end of the production cycle at approximately 85 weeks of age. The diets change based on egg production percentage, egg size, and feed consumption to ensure a high level of performance and that the desired egg size is maintained. When the pullets are placed in the house the photoperiod is increased from about 10 hours of light per day to 16 hours over a period of several weeks, where it is then maintained until the end of the production cycle. Daily care entails walking through the laying house identifying mortality, checking feeders and drinkers, collecting floor and system eggs (depending on the housing system), and observing flock health (Linares et al., Chapter 7).

The predominant laying hen housing system in the United States and globally has been the conventional cage for more than 60 years. However, the increased consumer interest in many countries in how food is produced, and the desire to address emerging animal welfare concerns by providing the hens with more behavioral opportunities, has moved the industry toward other production systems. These production systems can be viewed as varying on the intensive to extensive spectrum: enriched colony cage (also called a furnished cage), aviary, barn, free-range, pasture, and organic.

1.3.2.1 Conventional cage

The conventional cage system has transitioned over the years from high-rise houses with A-frame caging to stacked, belted caging (Fig. 1.5). Cages vary in size, but typically hold 5 to 10 hens. In the United States, under the animal welfare standards of the trade organization of the egg producers, United Egg Producers (UEP), hens are given a minimum floor space allowance (stocking density) of 67 in^2

Figure 1.5 A conventional cage house stocked with white laying hens. The water lines are located inside the cage while the feeder runs on the outside of the cage front. This stacked belted system has a manure belt between each tier to remove excreta while an egg belt moves the eggs in the opposite direction toward the processing plant.

(432.3 cm^2) per hen (UEP, 2017). Other countries may require different minimum stocking densities, as may the certifying bodies and egg buyers (e.g., restaurants, grocery stores, and food service) that set independent standards for egg production. A conventional cage has a nipple or cup drinker and a feed trough in front of the cage. Feed and water are delivered automatically to provide free access for the hens. The cage floor is sloped, allowing for eggs to roll to the front of the cage onto the egg belt, at which point the eggs are conveyed on multiple egg belts to the processing area.

1.3.2.2 Furnished or enriched colony cage

Furnished cages were developed in Europe in the early 2000s in an attempt to address concerns about the behavioral restriction imposed by conventional cages, which were banned in 1999 (with the ban effective 2012) in the EU. Initially, furnished cages were small cages similar in size and shape to conventional cages, but containing a perch, nest box, and a litter area for scratching and foraging. Over time the cages were enlarged, and the cage features became more standardized across cage manufacturers. These new larger systems, which house 60 to 100 hens per cage, are often referred to as enriched colony cages (Fig. 1.6).

The colony cage currently in widest use by the commercial industry is approximately 5 ft (152.4 cm) wide by 12 ft (365.8 cm) long with a nesting area, perches, and a "scratch" pad. Hens are provided with at least 116 in^2 (748.4 cm^2) of floor space per hen. The nesting area consists of plastic flaps that hang around a nest pad (usually made of Astroturf or rubber coated wire). The perches are located in the center of the cage and, depending on the cage manufacturer, may be made of molded plastic or metal and may be either square or cylindrical in shape. The scratch pad area is located at the opposite end of the cage away from the nesting area. Scratch pads vary in size and materials used, including Astroturf, heavy plastic sheets, and molded plastic. There may be claw abrasive strips (nail file bars) positioned close to the feed trough. Multiple nipple drinkers and feed troughs (typically two external feed troughs, one on each side of the cage) provide automatically delivered feed and water. Depending on the cage design, to encourage foraging behavior there may be an internal auger that drops feed on the scratch pad or there may be holes in the external auger that distribute feed onto a small area in the cage close to the feed trough. The cage floor is slightly sloped so eggs will roll onto the egg belt, with the fate of the eggs the same as for the conventional cage.

1.3.2.3 Non-cage systems: Aviary and barn

Indoor non-cage systems are classified as either aviaries or barns. These two systems have many similarities, with the predominant difference being the vertical space that is used in the aviary compared to the limited or no vertical space use in the barn. Under the UEP standards (UEP, 2017) non-cage laying hens are given a minimum of 1−1.5 ft^2 (0.09−0.14 m^2) of space per hen depending on the system type, although other certifying bodies may require additional space. In the EU

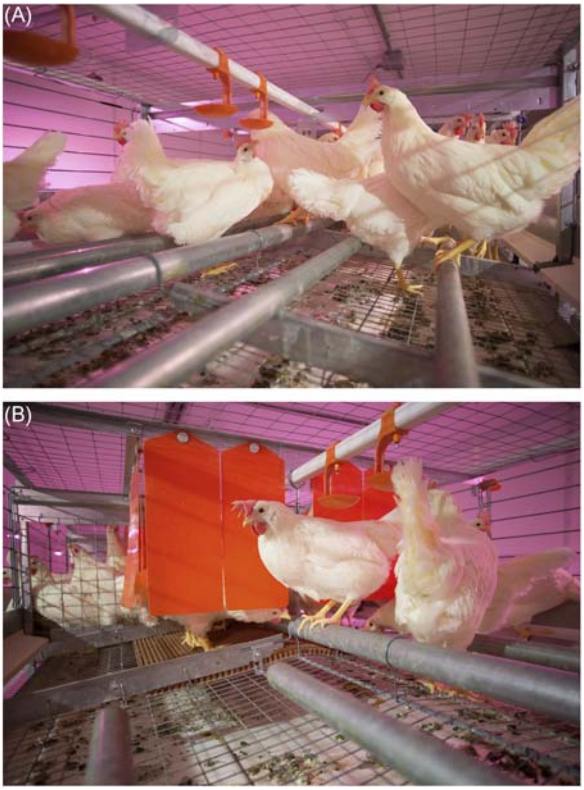

Figure 1.6 An enriched colony cage stocked with white laying hens. The enriched colony cage provides perches (A), a nesting area surrounded by plastic curtains with a nest mat (B) and a scratch pad (not seen). In this system, the water lines are inside the cage while the feeders run outside the cage on both sides; some designs of enriched colonies also have internal feeders.

(CEC, 1999), the minimum space required in any non-cage system is 9 hens per m^2 (1.2 ft^2 per hen). The barn system is an open barn that has a section of raised slatted or wire flooring with nest boxes, feeders, and nipple drinkers (Fig. 1.7), with manure belts underneath to remove excreta. The remainder of the floor is covered with a friable litter substrate that the laying hens can use for dustbathing and other behaviors such as foraging. Litter is not removed until the end of the production cycle, so manure in the litter stays in the house until it is depopulated. Perches are located throughout the barn. The laying hens have access to the entire house. Ideally they lay their eggs in the nest boxes, although they may lay eggs on the wire/slatted floor or litter area.

In an aviary system (Fig. 1.8), there are tiers in the house that provide vertical space on which the hens can stand and perch. There are numerous iterations of aviary systems available commercially. Some systems have doors that can be used

Figure 1.7 Brown laying hens in a noncage barn system. The nest boxes are located behind the orange nest curtains. The feed and water lines are located on the slatted area, which is a raised platform; the litter area is located in front of the slatted area. In this picture, pop-holes are located in the side-wall of the building to provide hens outside access, which means that this system is considered free-range.

to confine the hens inside the structural part of the aviary system for a period of time, for example to train them to lay their eggs in the nest or to administer vaccines. Other aviary systems are entirely open and do not provide a way for the hens to be confined. These are the two ends of the aviary spectrum, with numerous iterations in between. Irrespective of the exact aviary configuration, ramps, perches, and/or platforms are provided to allow the hens to navigate the different tiers. Each of the tiers consists of a wire or slatted floor with a manure belt underneath to remove the excreta from the system multiple times throughout the week. Nest areas, nipple drinkers, perches, and feed troughs are available on the tiers. The exact design and layout is determined by each manufacturer. The floor of the house has a litter substrate that the hens can access for foraging and dustbathing. As with the barn system, manure in the litter stays in the house throughout the production period. Ideally hens will lay their eggs in the nesting area, but eggs may also be laid in the system and on the litter floor.

1.3.2.4 Free-range, pasture, and organic

Free-range, pasture, and organic are specialty production systems that require the hens be provided with outdoor access. Free-range laying hens (Fig. 1.9) may be housed within an aviary or barn and provided access to the outside via holes in the side of the building (pop-holes). There are also systems where the hens do not have unrestricted outdoor access, but instead are allowed out into a covered veranda (porch) with sides made of mesh. Pastured hens may be given housing in the form of movable coops that are relocated around the pasture regularly to maintain good pasture condition and to prevent manure from building up in the soil that can lead

Figure 1.8 Brown laying hens in two types of multi-tier aviary systems. Aviary systems provide nesting areas, feeders, and waterers inside each tier of the system. In the first system (A), the hens navigate the system using the perches to move from the litter area on the floor to the top tier. In the second system (B) the hens move through the tiers by entering and exiting through the bottom tier via perches and solid platforms.

to the hens becoming infected with parasites or disease. The movable coop contains feed, water, and nest boxes for the hens, and provides them with shelter. Flock sizes vary from hundreds to thousands of hens depending upon the enterprise. The UEP does not have standards for free-range or pastured hens, so producers may instead follow a third-party certification program.

Of the three types of noncage systems, organic is the most stringent with defined standards; organic systems are either free-range or pasture-based. There have been numerous debates regarding appropriate outdoor access and hen stocking densities. The USDA-AMS (AMS, 2016) is currently in the process of further defining specific requirements for organic systems related to hen behavior and welfare considerations

Figure 1.9 Brown laying hens exiting a house through a pophole (left) and foraging outdoors.

(7 CFR Part 205). Additionally, requirements on land, feed, cleaning and disinfection substances, and egg processing must be followed to carry the organic label.

1.4 Welfare considerations in poultry production

Broadly speaking, welfare considerations and the associated research to address those considerations fall into three areas: ability to express normal behavior, good functioning (health, physiological normality), and feelings (especially pain and distress). In this section of the chapter, we briefly discuss some of the major concerns related to the welfare of egg and meat chickens, turkeys, and ducks. We do not attempt to cover all welfare issues, just those that are of significant current concern and that represent active areas of investigation. We should emphasize that the causes of many welfare problems are complex, and that as a consequence there are rarely "simple solutions." In many cases, the contributing factors to problems are still poorly understood. In addition, there are limited data for some welfare problems in terms of how prevalent they actually are on commercial farms in different regions of the world, making it difficult to determine how severe or pervasive the problems are. At present, most data come from European farms, and these may (or may not) reflect prevalence in other countries and regions.

Having said that, there are some general aspects of housing and on-farm management that can impact the welfare of all types of commercial poultry, although their degree of impact may depend upon the specific production system or interaction between system and type of poultry. These include air quality, thermal environment, lighting, flooring, water provision, nutrition, spatial restriction, social environment, enrichment, beak or bill trimming/treatment, human–animal interactions, and genetic selection and management for productivity:

Air quality—It is a welfare concern in indoor housing systems (reviewed in David et al., 2015a,b). Ammonia released from decomposing manure can lead to respiratory irritation and conjunctivitis; this problem is exacerbated in management systems where the manure remains in the house for a period of time (e.g., where there is litter that is not removed until the end of the flock cycle, or where manure drops into a pit below the cages rather than being conveyed away on a belt). "Poultry dust" (from feathers and skin, dried manure, feed, litter material, and other residues) can also cause respiratory problems and conjunctivitis, and tends to be a worse problem in systems with litter. In addition, dust can harbor toxins and disease organisms that can affect hen welfare.

Thermal environment—Thermal stress, and particularly high temperature and humidity, can cause discomfort, production losses, and mortality (Lara and Rostagno, 2013) in poultry kept either indoors or on the range.

Lighting—In indoor systems, poultry are usually raised in artificial lighting that may provide unusual photoperiods or very low levels of illumination, to improve productivity and to reduce the potential for particular types of problems (e.g., cannibalism in laying hens, broilers scratching one another). This can affect the birds' eye structure (eye enlargement) and/or potentially negatively impact them in terms of carrying out their normal behaviors.

Flooring—In systems where litter is provided, maintaining the litter in good condition is critical for foot health as well as respiratory and eye health (as discussed earlier). Wet litter contributes to problems such as footpad dermatitis and hock burns, and if lesions on the foot become infected bumblefoot (a painful foot inflammation) can develop. Birds can also experience foot problems from standing on wire for prolonged periods (hyperkeratosis, a thickening of the footpad which can then develop cracks that can become inflamed or infected).

Water provision—Various concerns have been raised about the provision of water in commercial houses. Nipple drinkers require birds to drink in an "unnatural" position, but more open sources of water can lead to wet litter, with its associated problems. Drinkers must be placed at an appropriate height to allow even smaller birds to drink, and training may be required to teach birds how to drink from some types of drinkers (i.e., those where the bird has to "trigger" the drinker to deliver water).

Nutrition—Typically, nutritional requirements are well understood and established for the poultry species, and significant nutritional deficiencies should therefore be uncommon under typical management conditions, although nutrient requirements for egg laying hens in the new housing systems and their impact on hen welfare are not yet well understood. Skeletal problems exist for all poultry and the role of nutrition in influencing or ameliorating those problems continues to be explored.

Spatial restriction—In indoor systems (or the indoor housing associated with free-range or pastured production), poultry are typically stocked at high densities, which restrict the amount of space available to each bird. Concerns about the effects of stocking density on welfare are broad, focusing on bird health, social behavior, movement, and responses to enrichment (Dawkins, Chapter 11). Poultry can be spatially and behaviorally restricted because of the size of their enclosure, which would be the case for caged laying hens, particularly in conventional cages.

Social environment—While ducks, turkeys, and chickens are all social species, the social environment in commercial production can pose challenges, particularly because of the large group size and high stocking densities (Estevez, Chapter 12). Of particular concern is competition for resources such as food and water, as well as the occurrence of problematical social behaviors that can cause injury to other birds, such as feather pecking, cannibalism, and excessive aggression.

Enrichment—Even when commercial production environments provide enough space for the birds to carry out postural adjustments and engage in local or long-distance movement, they may not contain the features that are behaviorally important to them, for example perches or material for foraging. The lack of enrichment can lead to frustration and contribute to outbreaks of behavior problems, e.g., feather pecking.

Beak or bill trimming/treatment—Most (but not all) poultry are beak or bill-trimmed/treated, which typically involves removing the distal 1/3 to 1/2 of the beak or bill to minimize injuries to other birds in the flock due to feather pecking, cannibalism, or excessive aggression. This procedure can be performed using either infrared treatment at the hatchery or trimming with a hot blade on the farm, but both procedures cause short-term pain (see Janczak and Riber, 2015; Nicol, Chapter 9).

Human–animal interactions—As discussed earlier in the sections describing systems, in the typical commercial environment there is rather limited contact between birds and humans. Caretakers walk through the house on a daily basis, but direct contact between humans and healthy birds is uncommon until the birds are caught/herded to be loaded on transport trucks (or depopulated) at the end of the production cycle. Human handling/contact at this time can be a source of injury, fear, and distress to the birds.

Genetic selection and management for production—The selection and management of meat birds for rapid growth and large breast size and of egg-laying hens for high rates of egg-laying contribute to the significant incidence of skeletal disorders currently seen in commercial flocks, particularly lameness in meat birds and bone breakage/damage in egg layers.

1.4.1 Welfare problems in meat chickens, turkeys, ducks, and laying hens

In this section, we briefly describe some of the most significant welfare concerns for each type of poultry, with reference to recent published reviews and papers. We note that any type of poultry, in any system, can be affected by diseases (viral, bacterial, and parasitic), and that this can be a significant source of distress and pain to the birds and result in mortality. Discussing the many diseases that can affect poultry is beyond the scope of this chapter, so we mention only those that are highlighted in the publications cited.

1.4.1.1 Meat (broiler) chickens

Welfare issues for meat chickens have recently been comprehensively reviewed by the Animal Health and Welfare Panel of the European Food Safety Authority (de Jong et al., 2012).

The main welfare problems identified by the Panel were the following:

- Musculoskeletal disorders—infectious and noninfectious disorders of the legs (mainly) and spine that can lead to lameness and gait disorders in flocks. These problems can be caused by many factors but genetic selection for rapid growth and conformation is a contributor, as are management practices designed to increase productivity such as high stocking density and dim/continuous lighting.
- Contact dermatitis—footpad dermatitis and hock burns, which when severe are painful; severe footpad problems can also lead to gait disorders.
- Ascites, pericarditis, and sudden death syndrome—health conditions that are related to selection and management for rapid growth and that result in mortality.
- Respiratory and mucous membrane diseases—associated with high ammonia levels.
- Thermal discomfort—air temperature and humidity are perhaps more critical for meat chickens than for other poultry types, since broilers have difficulty in dissipating heat due to their relatively large body mass and are thus very susceptible to heat stress.
- Behavioral restriction—due to space restriction, gait problems, lighting programs, poor litter quality (which can make the litter unsuitable for dustbathing or foraging), or lack of enrichment.

1.4.1.2 Turkeys and ducks

Welfare issues for turkeys and ducks have been less studied than for broiler chickens. However, since their housing and management is very similar to that of broilers, many of the concerns identified above also apply to ducks and turkeys.

Turkeys

Welfare issues for turkeys have been reviewed recently by Erasmus (Chapter 13) and Marchewka et al. (2013). Turkeys, such as broilers, are prone to footpad dermatitis as well as leg and skeletal abnormalities that can result in lameness, and these are affected by similar management factors (e.g., litter quality, stocking density, and lighting program). A particular concern for turkeys that differs from broilers is injurious pecking of other birds in the flock. Turkeys engage in aggressive head pecking, as well as feather pecking and cannibalism, and these behaviors can result in significant injury and mortality in flocks. This problem is managed via beak trimming, dim lighting, or both. As discussed earlier, these are welfare concerns in their own right.

Ducks

The most recent review of duck welfare issues was published in 2005 (Rodenburg et al., 2005), focusing on ducks in European duck husbandry systems (not only Pekin ducks, but also Muscovy and Moulard (mule) ducks, the latter of which are used for the production of *foie gras*). For Pekin ducks, many of the main welfare concerns identified in that review, and in subsequent publications on Pekin duck welfare (Colton and Fraley, 2014; Jones and Dawkins, 2010; Karcher et al., 2013), are similar to those for broilers, particularly leg problems and footpad lesions. The factors affecting these problems are similar to those for broilers, although for ducks the contribution of standing on slatted floors in systems where slats are used is of importance in addition to litter condition. Unlike broilers (but like turkeys), Pekin ducks do show feather-pecking behavior, and for that reason may be bill-trimmed.

An issue unique to duck production is related to providing open water sources, and this is probably the most controversial topic for duck welfare. Pekin ducks are usually raised with nipple drinkers to eliminate problems with water spillage like wet litter. However, they are not given water for preening, dabbling, or bathing, behaviors that they are highly motivated to perform. An open water source that is large and deep enough to allow bathing creates hygiene problems in a commercial house and becomes contaminated with feces. Experimental alternatives have been evaluated that provide the ducks with water that allows them to preen (and hence to maintain good eye, nostril, and feather condition), although not to swim; these include showers and troughs (Jones et al., 2009; Liste et al., 2013). However, even fairly shallow troughs can become contaminated with bacteria (Schenk et al., 2016) and thus create health risks.

1.4.1.3 Laying hens

Welfare issues for laying hens are more complex than those for meat birds, for several reasons. First, laying hens remain in production for a longer period of time than meat birds, which means that there is an expanded time scale for problems to develop and increase in severity. Second, pullets may be raised up until the time of production under different conditions than those they will encounter in the laying environment, potentially contributing to some welfare problems (Widowski and Torrey, Chapter 3). Finally, as we describe earlier, laying hens can be kept in a variety of different housing systems, ranging from cages to pasture-based production, and the risks for particular welfare problems differ by housing system. In this section we provide only a very general overview; the differential effects of housing system are discussed in more detail in Mench and Rodenburg (Chapter 10). Recent reviews of laying hen welfare issues can be found in Lay et al. (2011) and in LayWel (2006). Some key welfare issues for laying hens are as follows:

- Restriction of normal behavior—Conventional cages are the most behaviorally restrictive environment, since they prevent free movement and lack the resources necessary for hens to nest, perch, and forage. Enriched cages also restrict behavior in that they allow local, but not long-distance (e.g., flight) movement and, while they do provide perches and nests, the foraging area is typically not well-used due to its size and the lack of constantly available material in which to forage. Restriction of behavior can also occur in indoor non-cage systems due to management factors such as inadequate resources or high stocking density, but in general these systems allow long-distance movement and a range of behaviors.
- Abnormal behavior—Feather pecking and cannibalism, which lead to the need for beak trimming. Vent cannibalism can be a major source of mortality in hen flocks, and hens

with severe feather loss due to feather pecking are more susceptible to skin injury and have difficulty controlling their body temperature.

- Parasites—Although any type of poultry can be affected by internal and external parasites, a growing concern specifically for laying hens is infestation with poultry red mite, which can cause severe anemia and death. At present this is not an issue in the United States, but problems with red mite infestation in laying hen housing systems in Europe have increased dramatically in the last decade.
- Bone health—Poor bone health that results in hens being susceptible to long bone fractures and keel abnormalities (fractures and deviations, collectively referred to as keel bone damage) is increasingly considered to be one of the most serious welfare problems in commercial flocks (see review in Toscano, Chapter 8). A variety of factors appear to contribute to bone fragility, including genetics, nutrition, and production/housing environment both during rearing and lay.
- Foot problems—including hyperkeratosis, footpad dermatitis, and bumblefoot. The incidence of severe foot problems in laying hens is generally not as great as it is for meat birds, although bumblefoot is a very painful condition that can lead to the death of the infected hen.
- Respiratory and eye problems—associated with high dust and ammonia levels.

1.4.2 Other welfare issues

Although our review has focused on on-farm housing and production practices, there are also welfare issues "beyond the farm door" related to breeding, hatchery practices, and transport. These aspects of poultry production have perhaps been less studied with respect to welfare than rearing conditions, but are all of importance to ensuring bird welfare throughout the production chain.

Schwean-Lardner (Chapter 3) reviews welfare aspects of hatchery practices. As she notes, the brief period of time at the hatchery can be quite stressful for chicks and poults, involving multiple machine and hand-handling procedures. Beak trimming/treatment are usually performed at the hatchery; in a turkey hatchery, the poults' toe nails or toe tips may be removed using microwave energy to prevent birds scratching one another when older. This is a potentially painful procedure that can also affect the adult turkey's ability to balance. The snoods of male turkeys may also be removed at the hatchery to prevent later pecking injuries. A particularly controversial hatchery issue is the use of purpose-designed macerators to kill unwanted or sick chicks, a method that causes instantaneous death but which has been criticized and is therefore being phased out by some hatcheries.

Transport can occur during several stages of production—when chicks are transferred to the hatchery to the brooding house, from the brooding/pullet house to the rearing/laying house, and at the end of the production cycle when the birds are sent to the processing plant. Transport is stressful at any age, involving crowding, thermal challenges, noise, and vibration associated with vehicle movement (Weeks, 2007). These stressors can result in mortality, with meat birds especially affected by thermal stress when they are transported to the processing plant. End-of-lay (spent) hens may experience particularly high mortality during transport because of their general condition and bone fragility; in the United States, end-of-lay hens may be euthanized on farm rather than being transported, which raises issues about the best methods to use for killing large numbers of birds (McKeegan, Chapter 17).

Finally, there are a variety of welfare concerns associated with breeding stock. As background, chickens and ducks are naturally mated and so are kept in mixed-sex groups, while turkeys are artificially inseminated, with the toms and hens kept separately. Welfare issues for broiler breeders were recently reviewed by EFSA (de Jong et al., 2012) and many of the same concerns will apply to breeding flocks of other meat birds. A primary concern is severe feed restriction to maintain reproductive competence. Because meat birds have been genetically selected for rapid growth the parent stock become obese unless they are feed-restricted, but restriction causes chronic hunger. Even when feed-restricted, parent stock are susceptible to some of the same musculoskeletal problems as their offspring. There are concerns about aggression in mixed-sex flocks and other injurious social behaviors (scratching, cannibalism) that may require physical alterations of the birds (toe removal, beak trimming), as well as the handling of toms and hens that is required to perform artificial insemination procedures on turkeys.

1.5 Conclusions and implications

This overview has highlighted some of the main features of rearing systems and welfare issues for meat chickens, ducks and turkeys, and laying hens. However, it should be borne in mind that poultry housing and management practices are continuously evolving, and with them welfare concerns. This is particularly true for laying hen systems, as the egg industry moves away from conventional cages. However, meat bird production is also changing rapidly. The increasing demand for "antibiotic-free" poultry meat, for example, is driving changes in management in an attempt to find alternative ways to prevent or control disease in flocks, which has obvious implications for bird welfare.

Similarly, there is a small but increasing proportion of meat and egg chickens in the United States raised in either free-range or pasture-based systems because consumers will pay a premium for these products; in many cases these birds are also managed under organic standards. Very little research has been conducted on these production systems, although attention is now being paid to addressing some of the challenges (van de Weerd et al., 2009), including how the range should be managed and configured to attract birds to use it and to minimize disease transmission from birds and rodents, how to protect birds from predators and provide adequate shelter and shade, nutritional management, disease prevention and treatment (particularly in organic systems, where the use of conventional medications is extremely restricted even for the control of parasites; see Mullens and Murillo, Chapter 14), and reducing behavioral problems such as feather pecking. This last issue may become particularly critical in the next few years, given that in Europe there is increasing pressure to ban beak trimming of poultry even though feather pecking and cannibalism remain problems, particularly in cage-free and free-range systems (Nicol, Chapter 9).

In contrast, economic and environmental drivers in some countries may push systems toward even greater intensification. For example, several companies are now producing cage systems for broilers and these are being installed in developing countries like India and China. These systems have some potential welfare benefits for the birds, because they are configured such that the broilers can be automatically loaded into the truck for transport to the processing facility without ever being handled by humans. But some would argue that cages represent a "step backward," in that they restrict the birds' movement and do not allow them to perform litter-based activities like foraging and dustbathing.

In general, the future of poultry housing and management seems certain to be strongly affected by changing consumer and public preferences and perceptions (Vizzier-Thaxton et al., 2016), as well as the increasing involvement of multinational retailers in setting standards (and sometimes global standards) for poultry production practices. As systems evolve so too will welfare concerns, along with the research, technologies, and applications needed to address those concerns.

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Part II

Management: Hatch to slaughter

The effects of hatchery practices on the welfare of poultry

2

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2.1 Introduction

Commercial hatcheries have the most concentrated bird population of any poultry unit, albeit for a short time period. There are very few hatcheries compared to commercial farms, hence the choice of various procedures and management practices can have a tremendous impact (positive and/or negative) on bird welfare, both at the hatchery and potentially throughout the birds' life cycle. With regard to this latter point, Heier et al. (2002) found mortality levels during week 1 and even through week 2–5 of age to be at least partially dependent on the individual hatchery the chicks were derived from, although this was confounded by varying genetic strains at each unit in this work.

The time at the hatchery is likely very stressful for the chicks, as they are exposed to changes in temperature, sound, movement, humidity, handling, nutrition, vibration, etc. Research into many of these responses is limited and primarily focuses on biological functioning. There are a number of locations in the hatchery, and a number of procedures, where this impact may be the largest. This chapter will focus primarily on those areas, which include incubator and hatchery conditions (including light, temperature, and relative humidity [rH]), identification of genders prior to hatch, euthanasia of hatchlings and unhatched embryos, and rapid movement and drops from belt to belt, throughout the unit.

The length of time required between setting eggs in the incubator until time of hatch varies by species. Table 2.1 lists the approximate time of incubation for common poultry species. However, this is simply a guideline. Even within species, there are many factors that will impact this time, including variations for specific genotypes of birds, egg size (relationship to breeder flock age), ambient temperature, equipment manufacturer and type, and many other factors.

2.2 Egg handling prior to and during incubation

2.2.1 Egg storage

Eggs may be stored prior to incubation for varying lengths of time, either at the farm or at the hatchery. It is interesting that egg handling prior to incubation, in particular storage time, can have an impact on bird welfare later in life, particularly

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Table 2.1 Estimated incubation times for various poultry species

Chickens	21 days
Ducks*	28 days
Muscovy Ducks	35 days
Turkeys	28 days
Geese	28−33 days

*Other than Muscovy.
Source: Adapted from Clauer (2017).

with respect to biological functioning. In an experiment conducted by Goliomytis et al. (2015), storing fertile eggs for up to 16 days did not reduce hatchability of set or fertile eggs, but did result in a poorer humoral immune response later in life as compared to short-term storage (4 days). There also appears to be a relationship between storage length and storage temperature. Branum et al. (2016) showed that storage for longer periods at 22°C as compared to 15°C resulted in a reduction in hematocrit numbers, red blood cell numbers, and hemoglobin concentration, again suggesting that time and temperature of fertile egg storage are important in establishing immunity later in life.

2.2.2 Incubator and hatcher conditions

2.2.2.1 Temperature and humidity

Incubator and hatcher temperature levels certainly must be within manufacturer ranges in order for viable embryos to hatch. However, the literature has shown that minor variations in these levels may have long-term impacts on the biological functioning of the hatchling. For example, Groves and Muir (2014), using a meta-analysis, found a link between egg shell temperature during the incubation process and leg health in 6-week-old broilers, as determined by the latency to lie test. Their results indicated that using temperatures slightly lower than optimal temperature improved leg health later in life.

Barbosa et al. (2008, 2013) studied the impact of various relative humidity levels during the incubation stage. Although the work did not make a direct link to bird welfare, the authors found that as the relative humidity decreased, so too did egg weight. Altering levels of rH (48%, 56%, and 64%) showed that the percentage of yolk sac to chick weight also shifted, with the higher ratio found when 48% rH was used. Again, this was not directly linked to chick welfare, but it might be interesting at some time to assess hunger levels of newly hatched chicks and to understand if this ratio of yolk sac to chick weight has an impact on hunger levels.

2.2.2.2 Lighting

Various aspects of light, including duration, intensity, pattern, and wavelength, have impacts on the growing bird. A more recent area of discovery with regard to light is focusing on the impact that light can have on embryos during the incubation stage.

It is known that the embryo becomes sensitive to light at approximately 3 days of incubation. Light at this stage likely passes through the shell, then through to stimulate the pineal gland located in the center of the brain tissue. The pineal gland secretes melatonin, which in turn is involved in the production of many hormones in the body, including those involved in immune function, reproduction, and growth (Özkan et al., 2012b).

In a traditional hatchery eggs are incubated in dark machines and, with the exception of times when the door must be opened, embryos are not exposed to light (Archer et al., 2009). However, research suggests that the addition of light has a number of benefits. Archer and Mench (2013) exposed fertile eggs to varying day-lengths in the incubator, including 12, 18, 23, or 24 hours of light per day at 550 lux intensity. The hatched birds then underwent a variety of stress tests at either 3 or 6 weeks of age. The stress hormone corticosterone was lowest when eggs were exposed to a 12-hour light diurnal rhythm. In addition, these same birds demonstrated a lower asymmetry score, a test which Møller et al. (1995) found related positively to developmental or embryonic stress. This result was also noted in Archer et al.'s (2009) study. Archer and Mench's 2013 work also found a relationship between the 12-hour light program in the incubation stage and improved immune function later in life.

After the importance of light exposure during the incubation stage was established, the research focus then was on at what stage of incubation light should be added. Özkan et al. (2012a) provided light in the incubation stage either during the entire period or during the final week, and compared the results to eggs incubated in the dark. Important differences were found, particularly with the embryos given a light/dark cycle for the entire period. The light/dark incubation resulted in the establishment of a melatonin rhythm in these embryos compared to those incubated in the dark. Additionally, the light/dark incubated embryos had lower corticosteroid responses compared to the responses noted in either embryos lit only during the last week or kept in complete darkness. The authors attributed the latter response to the full light causing changes in the hypothalamic−pituitary−adrenal axis that did not occur in other embryonic treatments. However, interestingly, no differences were noted in this case in asymmetry (developmental stress) or malondialdehyde concentrations (oxidative stress).

Other research has found differences with regard to time of embryonic light program initiation. Archer et al. (2009) examined chicks from incubation programs including 24 hours of dark, 12 hours of light, or 24 hours of light, but found no differences in hatchability, mortality, feed consumption or efficiency of conversion, gait score (walking ability) or behavioral activity. Interestingly though, the pattern of feeding differed slightly, as both treatment groups exposed to incubation light appeared to feed more after lights came on, which was also noted in other research (Archer and Mench, 2014a). This increase in postdark feeding has been noted in other types of research and has been linked to the development of strong diurnal rhythms (Schwean-Lardner et al., 2014). It is very exciting that the exposure of embryos to light/dark cycles may result in the development of these rhythms very early in life. Further evidence of this rhythm was noted with significant melatonin rhythms in chicks when embryos were exposed to 12 hours of light versus complete dark until 19 days of chick age (Archer and Mench, 2014a), and in chickens reared under either 16 hours of light or constant light when embryos were given a 16 hour light and 8 hour dark period throughout the incubation stage (Özkan et al., 2012b).

Affective states of the chick and bird are also influenced by light/dark incubation cycles. Archer and Mench (2014b) clearly demonstrated that embryos are periodically exposed to light when eggs are naturally incubated, and the result is a reduction in fear and stronger ability to handle stressful challenges later in life. The duration of light during incubation is another decisive component to the reduction in chick fear levels achieved with the use of in ovo lighting. Archer and Mench (2017) found that chicks exposed to either 1 or 6 hours of light in ovo demonstrated inconsistent reductions in fear as measured by a number of fear-related tests, but those exposed to 12 hours of light showed consistent reductions in fear.

Birds have the ability to sleep in a unihemispheric sleep pattern, and light in the incubation stage appears to modify how this occurs. Bobbo et al. (2002) found that providing light during the incubation stage meant that chicks slept with the right eye open, while dark environments meant the left eye was open. Archer and Mench (2014b) also found that the provision of light resulted in lateralization or direction of escape after the release from a dark box. These two studies indicate significant involvement in brain development occurring with the addition of incubation light.

Many other reported benefits are not directly related to welfare, but clearly indicate that light and light/dark cycles during the incubation stage have important developmental advantages for the hatchling. Growth hormone expression is heightened and the growth of the embryo is stimulated with light during the incubation stage, which appears to reduce time to hatch (Rozenboim et al., 2013). Chick eye weight increased when embryos were incubated in the dark (Archer et al., 2009). This again indicates the possibility of lack of diurnal rhythm development, since eye development is affected by melatonin rhythms.

2.2.3 In ovo nutrition

In ovo injections have become a large part of commercial hatchery procedures, and the products injected vary widely, particularly to stimulate growth and immune functioning. Undoubtedly, vaccine injections in ovo (Fig. 2.1) develop immune responses in the hatchling. The vaccination in ovo results in a reduction in handling, and hence stress, on the newly hatched chick. There may be a weak link between in ovo injection of nutritional-based products and bird well-being. Injecting trace minerals may increase bone mineralization (Oliveira et al., 2015), which may influence bone quality later in life. Vitamin E injections on day 14 of

Figure 2.1 SANOVO VAX machine-infertile egg remover and vaccine optimizer. This advanced equipment can recognize and remove infertile eggs and early dead embryos prior to the inoculation procedure, then administer the vaccine in ovo prior to transfer to the hatcher. *Source*: Courtesy of Sanovo Technology A/S.

incubation (Salary et al., 2014) or folic acid on day 11 of incubation (Li et al., 2016) may improve immune function of the hatchling.

2.2.4 In ovo audio stimulation

It is possible that other stimulation during the incubation phase could also impact welfare of poultry species. Sound was used (Chaudhury et al., 2009) in the form of either species-specific sound or even music for 15 minutes per hour from day 10 of incubation onwards. Interestingly, synaptic density actually increased in treatments with sound exposure. The authors relate this increase to an improvement in synaptic plasticity, and hence a better ability for the chicks to form memories later in life.

2.3 Embryonic sensibility

At what stage of development does an embryo suffer? There continues to be debate regarding the stage of incubation in which welfare of the embryo becomes an issue. Yet it is an important welfare consideration in commercial hatcheries. Unhatched eggs are disposed of, but the methodology used for these eggs should differ if the embryo can experience suffering. Hence, this is an ethical dilemma faced in the hatchery industry. Numerous reports suggest that it may occur as early as mid-way through embryonic incubation, so requirements for specific humane-killing techniques are sometimes based on the ability to suffer as early as the 50% stage of incubation (AVMA, 2013; Close et al., 1997). Science has not come to a clear consensus to support this recommendation to date.

In order to attempt to come to a conclusion, we should understand what the definition of suffering is, and that may also be a contentious issue. It is not necessarily just "pain" that causes suffering of an embryo, but also the ability to experience noxious stimuli (Mellor and Diesch, 2006).

The review by Campbell et al. (2014) of the subject area points out that this determination is difficult because we first must understand when suffering can be felt, and to do this, the embryo must be conscious. Their questions included asking at what stage of development the embryo has the level of consciousness required for it to experience suffering. For that to occur, there must be adequate subcortical−cortical neural connections, and we do not know when that occurs in the avian brain. Mellor and Diesch (2006) reported that both sentience, meaning that the neural development in the embryo is functional and able to transmit neural impulses to the brain and convert them into some form of sensation, and consciousness, in that the embryonic brain is able to comprehend or perceive the sensations and must sense the negative form of the sensations, must exist in the embryo for suffering to occur.

Why is this determination so difficult? Let us start with what we do know. We know that neural tissue differentiation does occur during the avian embryonic stage, but a form of tissue maturity must be present prior to the ability to perceive sensations (Mellor and Diesch, 2006). The central nervous system begins to form as early as day 2, maturing some time prior to hatch on day 21. The embryo's neurological sensory mechanisms, including tactile (day 6), proprioceptive-vestibular (day 8−10), taste (day 12), auditory (day 12−14), visual (day 18), and olfactory (day 20) (Deeming, 2011; Mellor and Diesch, 2007), develop over stages. Mellor and Diesch (2007) described maturation of the embryonic brain waves as a progressive advancement. The brain waves, measured via electroencephalograph waves, are initiated as early as day 13−14 of incubation, then go through a progressive developmental series in the embryo. Erratic spikes appear by day 15, and by the 18th day of incubation, EEG waves similar to slow/fast sleep waves appear. By the 19th−20th day, the EEG waves become similar to the waves noted in the hatchling during sleep. Muscular activity appears to begin sometime in the second trimester, although those responses may be an autonomic reflex rather than a reaction to stimuli (Deeming, 2011).

So does this information help to determine the age of ability to suffer in embryos? Mellor and Diesch (2007) believe that the maturity of the neural anatomy in the avian embryo is lacking for at least the first half of the incubation phase, and that electroencephalograms indicate the avian embryos are in a sleep-like or unconscious state under the function of a type of neurosuppresive mechanism until after hatching. They also note that the EEG waves found during day 18−20 of incubation are similar to those noted in chick sleeping patterns, further providing evidence of a sleep-like stage prior to hatch. However, the authors also note that this is not a clear area of science. For example, they note that during this latter phase, the embryos actually have an ability to vocalize, which may indicate that some degree of awareness has been achieved, and the embryos must initiate the hatching process, which may require some level of consciousness.

2.4 Chick processing

2.4.1 Handling

Chick movement throughout the hatchery can be very quick and can involve the chicks dropping between various belts. For most commercial hatcheries, the majority of this movement takes place via mechanical means, with moving belts to move chicks along the process. Human handling may only take place for placement on treatment machines or for assessment of chick quality. Knowles et al. (2004) focused on affective states of chicks at a group of hatcheries, and found that righting time (related to chick disorientation) differed between hatcheries rather than by strain, and between differing sections of the hatchery line. The authors used an accelerometer to determine the speed of mechanical movement in the hatcheries and found it differed throughout the sections within hatcheries. Drop heights varied between hatcheries and ranged from 7 to 55 cm, but the increased height only resulted in a tendency for chicks to not stand postdrop. The authors also examined the relationship between handling at the hatcheries and chick fear, using tonic immobility testing. The data did not indicate a consistent relationship, with chicks from one hatchery remaining in the tonic state for a shorter period of time posthandling (suggestive of less fear), chicks from two hatcheries remaining in the tonic state for a longer period of time posthandling (suggestive of higher fear), and chicks from the remaining hatcheries not demonstrating any difference posthandling. Differences in handling between hatcheries did not increase chick mortality, and no evidence existed to indicate an increased amount of suffering based on handling at the hatchery. Overall, the authors stated that hatchery maintenance is likely the primary factor involved in chick welfare, including injury from drops, mortality, and affective states such as fear and disorientation.

Jones and Faure (1981) reported that human handling could reduce fear levels in layer and broiler strains. It is important to remember, however, that the handling in this work involved daily handling over a 35-day period, and the authors suggested that habituation played an important part in this adjustment. Short-term handling at the hatchery is likely therefore not resulting in the same habituation to humans.

2.4.2 Procedures

2.4.2.1 Beak treatment

Arguably, an effective management tool to reduce the impact of aggressive behavior and control cannibalism in birds is treating the beaks of the birds to eliminate the sharp hook (Hester and Shea-Moore, 2003). This area is likely to be one of the main welfare issues facing the industry in future production systems (Vizzier-Thaxton et al., 2016), and suggestions have been made that other management techniques should be employed when possible as control measures (Fraser et al., 2013). These may include genetic selection to identify bird strains that do not demonstrate these negative behaviors (Glatz, 2005; Hester and Shea-Moore, 2003), but to date this has not been fully successful.

While welfare of beak treated birds can be improved through a reduction in mortality and cannibalism, the effects of the procedure itself should also be considered. The beak of a bird is highly innervated and contains many sensory receptors (Kuenzel, 2007), and both short-term and chronic pain should be considered. The beak is also used extensively in many maintenance behaviors of the bird, so treating might impact aspects of the bird's life, such as ability to grasp feedstuffs or engage in normal preening behavior (Kuenzel, 2007; Kuo et al., 1991).

Commercial hatcheries that beak treat birds typically will use one of two techniques—hot-blade (HB) trimming or infrared beak treatment (IRBT). HB trimming uses a hot blade (approximately 750°C) to burn and cauterize the beak tip, and can be done manually or with an automated machine. The procedure results in an immediate shortening of the beak, but may also leave an open wound which could allow bacterial penetration. IRBT exposes the beak tip to an infrared light energy, which kills the beak tip tissue, causing it to slough over a period of approximately 7−14 days (Marchant-Forde et al., 2008; McKeegan and Philbey, 2012). This allows time for the tissue at the tip to heal, leaving no open wound (Hester and Shea-Moore, 2003). However, the cost of the equipment may prohibit smaller hatcheries from using this technique.

Hot-blade trimming

Unlike IRBT, HB trimming is performed at a multitude of ages, but the least negative impact occurs when the trimming happens early in life such as at the hatchery (Gentle, 2011; Schwean-Lardner et al., 2016). As with other hatchery equipment, maintenance is important to ensure proper temperatures (Maizama and Adams, 1994) and exposure time for cauterization (Christmas, 1993; Lunam et al., 1996), and standard operating procedures and proper training should be followed to ensure that the treatment is effective, the amount of beak removed is controlled, and variability is reduced (Dennis and Cheng, 2012).

HB trimming results in short-term pain (Gentle, 2011; Marchant-Forde et al., 2008; McKeegan and Philbey, 2012), typically judged by behavioral changes posttreatment. Interestingly, there appears to be a short "pain-free period" almost immediately after the treatment is applied (Gentle, 2011), so discussions of including pain medications at the time of treatment may not be of value.

HB trimming alters the behavior of the birds, with a number of studies showing reduced activity, pecking, and feed intake posttreatment (Dennis and Cheng, 2010; Gentle et al., 1997; Marchant-Forde et al., 2008). In some cases, behavioral changes, possibly indicative of pain, disappear after some time. Dennis and Cheng (2010) found reductions in pecking and pecking force after HB trimming at 2 days and again at 3 weeks posttreatment, but differences disappeared by 4 weeks of age. The differences noted in behavior in the literature could relate to differences in procedure severity, age of trimming, adjustment to the new beak shape, etc., and care should be taken in comparing studies to examine the exact procedures used. In general, the negative impacts of HB trimming appear to be more severe than with IRBT (Janczak and Riber, 2015).

Infrared beak treatment

IRBT impacts a large area of the beak (36% reported by McKeegan and Philbey, 2012). The procedure may cause short-term pain in chicks (Marchant-Forde et al., 2008) although there appears to be some disagreement in the literature. The pain is not chronic in nature (Hester and Shea-Moore, 2003; McKeegan and Philbey, 2012), and it appears that limited nerve regeneration can occur in the treated tissue (McKeegan and Philbey, 2012). The procedure does not result in the formation of neuromas (McKeegan and Philbey, 2012), which are considered to be the cause of chronic pain in beak trimmed birds.

The literature is also not consistent in terms of the impact of IRBT on bird behavior. In a study by Gentle and McKeegan (2007), the behavior of broiler breeder chicks treated with either IRBT or HB did not differ from untreated birds for the following 6 weeks. Other research indicates conflicting results. Reduction in ground pecking and severe feather pecking, but increasing incidence of gentle feather pecking, occurred when IRBT birds were compared to untreated birds (Hartcher et al., 2015). This resulted in improved feather coverage of hens (Hartcher et al., 2015), which is often used as an indicator of severe feather pecking (Vizzier-Thaxton et al., 2016). Differences in eating and drinking behaviors were also apparent for the first week after treatment in both HB and IRBT birds (Marchant-Forde et al., 2008). Posttreatment beak abnormalities are less common when hatcheries ensure that proper quality control (i.e., equipment settings) is used with the IRBT system as compared to HB (Carruthers et al., 2012; Marchant-Forde et al., 2008), and beak length is more consistent (Carruthers et al., 2012). Once again, however, this point is not consistent in the literature. Kajlich et al. (2016), in a study of mortalities on commercial cage-free farms, found that over 40% of hens necropsied had a beak abnormality post-IRBT (differences in shape and/or length differences between top/bottom beak).

IRBT equipment is complex (Fig. 2.2), and beak anomalies can certainly arise if inappropriate settings are used. IRBT treatment must be specific for species, strain, flock age, beak pigmentation, hydration level, and even housing system. Standard operating procedures (specific treatment plate and reflective mirrors to ensure a correct bottom beak treatment for each combination) for various combinations of these factors should be specific to each situation, and it is important that hatcheries monitor quality control and field evaluation processes to validate the efficacy of the treatment.

2.4.2.2 *Toe treatment*

It is not uncommon for birds to experience a range of scratching severities in the commercial turkey industry (as birds may attempt to fly, or climb on another) or broiler breeder industry (during mating). A procedure commonly used to reduce the incidence and severity of these scratches (which is both an economic concern and, because of the potential pain and increased likelihood of infection, a welfare concern) is to remove the bird's toe nails or toe tips (McEwen and Barbut, 1992; Owings et al., 1972). The mechanisms for doing this have changed substantially,

Figure 2.2 Nova-Tech Poultry Service Processor (PSP) equipment used for infrared beak treatment (IRBT). Chicks are placed on this equipment after hatch, where the tip of the beak is exposed to an infrared light. Vaccination also takes place on the same equipment, reducing the need for manual handling of chicks.
Source: Courtesy of Nova-Tech Engineering LLC.

and currently some but not all poultry (this practise is more common in the breeder and turkey industry) have toes exposed to a microwave energy for this treatment. Exposure to the microwave claw processor (MCP) machine results in tissue dying and sloughing off over a period of 1–3 weeks (Gorans, 1993).

The MCP procedure significantly reduces scratches (by approximately 30%) in turkey hens (Fournier et al., 2012, 2015), but also impacts behavior, with trimmed hens resting more than their untrimmed counterparts at 3 days of age. It was not clear if the reduction in mobility of the young female poults was a pain response or other sensation, or if balance was affected. No differences in hen behavior were noted after this time, however, to 20 weeks of age.

While the reduction in scratching for commercial birds is an improvement with regard to welfare, the bird could potentially be negatively affected by toe treatment in other respects. The potential exists for the procedure to be painful and to remain so throughout the life of the bird. In humans, the toes are important in maintaining balance (Chou et al., 2009) and they potentially play a similar role for birds. Studies have also shown that early turkey flock mortality may be higher in treated versus untreated birds (Newberry, 1992), although this study used a hot-blade to clip the toes as compared to the more modern MCP. As well, the amount of tissue, equipment maintenance, and the standard operating procedures employed at the specific hatcheries could certainly affect the outcome for the birds.

Fournier et al. (2012, 2014, 2015) also studied the responses in heavy tom turkeys to microwave toe treatment. Similar to the females, treated birds ate less, rested more, and walked and stood less than untreated birds at 1 day of age. Toms at older ages (133 days of age) did not differ in comfort or feeding behavior, but a difference was noted in the percentage of time they spent standing versus walking, with the trimmed birds standing more. The authors attributed this to a possible lack of ability to balance because of the trimmed toms' shorter toes, although pain could not be ruled out. Interestingly, no differences in mobility (tested by gait score) or posture were noted at this age. Furthermore, no benefit was noted in terms of reducing the number of carcass scratches in heavy toms, suggesting that the technique does not have the same benefit for heavy tom production as it does for hen production.

2.4.2.3 Methods of humane killing

Chicks may be killed at commercial hatcheries for a number of reasons, including that the chicks are sick or injured and also to dispose of unwanted male egg-production line birds. To ensure the best well-being possible, any methodology used to humanely kill unhatched embryos or just-hatched chicks should be as pain and stress-free as possible (Bates, 2010; Jaksch, 1981; Leenstra et al., 2011). More factors than welfare, however, are generally used in the decision of these methodologies, and Jaksch (1981) identified a number of criteria which include speed, the reliability to achieve a quick death, as painless as possible, ease of use to ensure it is implemented, economy, and safety for the staff and for the environment, and ethics. Commercial hatcheries focus on two primary methods of humane killing, maceration and the use of inhalants.

Maceration

Maceration of chicks is not legal in some areas of the world (Buhl, 2016), but if conducted properly with appropriate and well-maintained equipment, maceration or homogenization will likely result in the quickest death for chicks, and involves no or minimal human handling (Jaksch, 1981; Vizzier-Thaxton et al., 2016). Hence, in terms of the definition of euthanasia, this methodology meets the criteria. As with many other procedures and equipment at the hatchery, proper maintenance and usage is essential for proper functioning of the equipment. However, the method has received extensive criticism from an aesthetic point of view, and for that reason, many hatcheries are removing the equipment and looking for alternatives, despite the fact that death is almost instantaneous.

Inhalation agents

The use of gas inhalation for asphyxiation, particularly carbon dioxide, for humane killing of chicks and poults appears to be of interest in place of maceration (AVMA, 2013; Vizzier-Thaxton et al., 2016). The research work described later has been conducted to assess the effectiveness of the use of carbon dioxide in the humane killing of chicks, but to my knowledge, this has not been repeated with turkey poults.

Typically, inhalants do not result in immediate unconsciousness and may result in distress in the animals (AVMA, 2013) as the gas is aversive. Many factors must be taken into consideration if an inhalant is to be used for humane killing, such as appropriate displacement rates and gas concentrations in appropriate sized containers, and knowledge of both the inhalant properties and the biological systems of the birds to assess if the use of prefilled containers or gradually filled containers is more humane (AVMA, 2013). Unconsciousness via the use of inhalants may reverse after removal from the container, so it is especially important to confirm death in poultry species.

Evidence exists that indicates neonates may not be as susceptible to gas inhalants as older animals (AVMA, 2013), hence hatchery decisions and standard operating procedures must be based on scientific evidence derived from day-old chicks. Concentrations of the gas may need to be substantially higher (AVMA, 2013 reports 80%−90%) than needed in older birds, with a longer exposure time.

Focusing on day-old chicks, it is clear that the gas concentrations and methodology used will vary in effectiveness. Carbon dioxide is the most common gas used as an inhalant agent for euthanasia at hatcheries, and AVMA (2013) lists CO_2 as an acceptable methodology with conditions for unpipped eggs and newly hatched chicks. The gas itself can have an anesthetic impact, but can be aversive to the animals resulting in distress (AVMA, 2013; Conlee et al., 2005) and pain in some species (Conlee et al., 2005).

Raj and Whittington (1995) tested various gas mixtures and monitored time to loss of posture in day-old chicks. The authors found that carbon dioxide, with or without argon (containing 1%−2% residual oxygen), resulted in loss of posture in under 2 minutes, argon alone took approximately 3 minutes, and altering gas concentrations could take up to 7 minutes to reach loss of posture.

2.5 Methods to reduce unwanted chicks—sexing of embryos

Regardless of the technique, the killing of large numbers of male chicks at commercial hatcheries is a topic that draws considerable criticism and is an ethical dilemma. This topic has been identified as one of the primary areas of welfare concern in the commercial egg industry (Vizzier-Thaxton et al., 2016). Because of this and a concern for welfare of chicks, a considerable amount of focus is now directed toward sexing of embryos in ovo. To the author's knowledge, the techniques are not yet commercially available, but technology is drawing closer.

The techniques used are variable and have advanced over time. This is important for economic reasons, but also possibly for welfare of the embryo if suffering can occur at the time of testing for sex determination. Identification prior to incubation would be the best case scenario (Burkhardt et al., 2011).

Arnold et al. (2003) used the blastoderm or vitelline membranes for specific gene analyses to determine gender in embryos. Tran et al. (2010) reported on a technique that withdrew allantoic fluid at 17 days of incubation, and used radioimmunoassay (RIA) technology to determine embryo gender. Infrared spectroscopic techniques to examine DNA levels were reported in 2011 (Steiner et al., 2011), and Weissmann et al. (2013, 2014) tested contents for estrone sulfate, which is higher in females, and accurately identified gender 84% of the time in eggs that had been incubated for 8 days, with the accuracy increased to 98%−100% by day 9 of incubation. As new techniques are emerging, it appears that the identification can be done earlier. Göhler et al. (2017) have established a technique that uses a nondestructive optical technique for birds that have specific gender colors. This can be performed at 14 days of incubation and has a success rate of 97%. Galli et al. (2016), using near-infrared Raman spectroscopy, reported 90% accuracy at 3.5 days of incubation, and this process can potentially be automated in the future for commercial application in hatcheries.

2.6 Early posthatch feeding

The traditional methodology posthatch, with regard to feed and water access, is to allow the chick to utilize the yolk sac as a nutrition source, which means that feed and water are not provided until arrival on-farm (24−72 hours typically) (Nielsen et al., 2011). New hatchery technology is appearing in the poultry industry however. For example, systems now exist that allow chicks immediately posthatch to drop from the top tray of a stacked unit into a second separate tray, where access to feed and water is given. An example is shown in Fig. 2.3. The chicks are then taken

Figure 2.3 HatchTech HatchCare equipment allowing access to feed and water immediately posthatch. Chicks hatch in an upper tray, then move to the lower tray, where feed and water are available to the chicks.
Source: Courtesy of HatchTech bv.

to the processing line for sorting, sexing, etc. Other systems actually allow hatch on-farm, again allowing immediate access to nutrients.

What do we know about how this immediate access influences the welfare of the chick? Providing feed at the hatchery does not influence heterophil:lymphocyte ratio (Gonzales et al., 2003) as compared to unfed birds. No difference in corticosteroid levels between chicks provided early feed and those not fed have been noted (Gonzales et al., 2003; Tong et al., 2015). Both of these findings suggest that the lack of feed during this time may not be stressful. We have no scientific evidence to note if hunger could potentially exist during this time.

Disease resistance may be improved through improvements in immune function when chicks are fed early in life. There could be numerous mechanisms that could potentially influence this. Providing early feed to chicks rather than fasting them for 48 hours can result in the proliferation of lymphocytes (Dibner et al., 1998). Feeding the young birds speeds usage of the yolk sac (Bhanja et al., 2009; Noy et al., 1996), which could directly improve passive immunity (Panda et al., 2015), increase levels of endogenous hormones and spark the differentiation of B-cells and other immune cells (Dibner et al., 1998). However, there is no evidence of reduced flock mortality when early feeding systems are used (Gonzales et al., 2003).

How quickly an embryo hatches may influence maturity of the developing embryo. For example, Van de Ven et al. (2013) found that although hatching at either 468, 483, or 498 hours had no influence on chick body weight or yolk sac weight, organ weights did appear to be heavier, and hence further developed, than those of chicks that hatched earlier. However, the chicks that hatch earlier in the incubation stage may not be as developmentally mature, and may benefit from access to feed at the hatchery more so than those embryos that hatched later (Careghi et al., 2005; Van de Ven et al., 2013).

Tissue development may be impacted by early nutrition, which could influence health in a positive manner throughout life. Feeding at the hatchery results in an increased tissue weight of the heart, liver, intestinal sections, and lungs as compared to chicks hatched in a traditional system (Gonzales et al., 2003; Bhanja et al., 2009; Van de Ven et al., 2013). Additionally, an increase has been noted in small intestine dimensions such as length, villi height, and crypt depth (Gonzales et al., 2003).

2.7 Chick transport conditions

Traditional hatcheries are often responsible for transporting chicks to farms. Study into chick welfare resulting from transport appears to be limited, but there are indications that biological functioning in particular may be impacted.

The vehicles used for this transport are often expensive (Quinn and Baker, 1997), with the ability to control temperature and relative humidity. However, Nazareno et al. (2015) found significant variability in the thermal dynamics inside of chick transport vehicles. In their study, while relative humidity was targeted to be held between 55% and 75%, areas of the truck were actually as low as

40%–60% and as high as 89% and 90%. Similarly, temperature varied, and temperatures inside the chick boxes tended to be lower than the truck set point. As the authors point out, this is particularly concerning, as chicks have little control of their own body temperature at this stage of life.

The length of the trip to farm may have multiple influences on the chicks, including related to well-being. While not all measures in their study were directly welfare related, Bergoug et al. (2013) reported that trip lengths of either 4 or 10 hours reduced chick weight as compared to 0 hour transport, but this was not reflected in dehydration level (as measured by hematocrit), feed intake, efficiency of feed conversion or even flock mortality. Khosravinia (2015) exposed chicks to travel distances of 200, 400, 600, 800, or 1000 km, and found a number of negative responses to increasing distances indicating an increasing level of physiological stress in the chick with an increased travel distance. The results of the study included a linear reduction in body weight with increasing distance, a quadratically shaped reduction in yolk sac, with losses more severe after 800 km, and reductions in serum glucose over distance. Valros et al. (2008) attempted to examine a number of welfare indicators resulting from long (14 hour) versus short (4 hour) transport trips in laying breeds. Their results were not consistent, but offered some indication that behavior on farm changed with trip length. In particular, the chicks exposed to the long transport times perched sooner and demonstrated a reduced willingness to feed than did chicks exposed to the short transport, both of which may suggest a higher fear level. However, tonic immobility, often used to quantify fear in bird species, did not differ. The authors in this latter trial suggest that more study is required to truly understand the behavioral effects of long transport on chicks.

As with many other aspects of welfare at the hatchery, research focusing on transportation effects on bird well-being is limited. For example, at the time of drafting this chapter, no research was found directed at the effects of vibration on chicks, despite there being considerable work in this area in market-aged birds.

2.8 Conclusion

Because of the huge number of birds hatched at commercial hatcheries, their potential to impact bird welfare is immense. The concept of "additivity of stressors" (McFarlane et al., 1989) means that stress occurring at the hatchery phase of life could magnify stressors later in life, multiplying the effects of other stresses and potentially reducing the ability of birds to cope.

In the future, hatcheries may look different. Genetic selection for reductions in severe pecking, or better understanding of bird behavior and improved management skills, may eliminate beak treatment procedures. Understanding how to determine gender prior to embryonic consciousness would reduce the humane killing of large numbers of chicks. Within the current structure of hatcheries, the importance of proper hatchery maintenance and strict use of standard operating procedures on chick welfare cannot be overstated.

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Rearing young birds for adaptability

3

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3.1 Introduction

The rearing period is critical for behavioral and physiological development of poultry species. After undergoing various multiple procedures at the hatchery, chicks and poults are transported; placed in a novel environment with same-age conspecifics; and must learn to eat, drink, and develop appropriate social behavior in groups of tens, hundreds, or thousands. This period of the bird's life is often overlooked, yet, factors related to handling, housing, feeding, and social experiences can have significant consequences on birds' adult behavior, stress physiology, musculoskeletal and neuromuscular development and health, and may even influence that of their progeny. Increasing interest is being paid to effects of early life experiences on birds' adaptability, particularly with regard to the laying hen. Innovative methods of applying traditional ethological methods and development of novel technologies are enabling researchers to study the lasting effects of these early experiences and make science-based recommendations for the rearing of chickens and turkeys to improve billions of birds' welfare.

3.2 Preparing pullets for laying housing systems

Hens can be adaptable to different housing systems during lay, although this is highly dependent on their housing and experience during rearing. Hens in noncage systems are at a considerable risk for injury, especially keel fracture (Sandilands et al., 2009) and mortality (e.g., Sherwin et al., 2010; Weeks et al., 2016), compared to those in cage systems. Some solutions for mitigating these problems lie in improving design and management strategies for layer housing, and in matching system and management with genetic strain of bird (Weeks et al., 2016). Increasingly, more attention is being paid to the behavioral and physical development of chicks and pullets destined for complex housing as adults. Practical experience indicates that it is imperative that hens housed in complex aviaries also be reared in complex systems, as both their cognitive and physical development require it (Janczak and Riber, 2015). This is particularly critical when food, water, and nest boxes are located on different levels of the aviary, since difficulty in accessing the levels increases the risk for emaciation, dehydration, and floor eggs

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(Tauson, 2005). Additionally, good welfare in noncage systems requires that hens are calm and adapt well to novelty. Fearfulness is particularly problematic in large groups since it is associated with feather pecking and can lead to panic resulting in pile-ups, smothering (Barrett et al., 2014; Bright and Johnson, 2011; Richards et al., 2003), and injury (Harlander-Matauschek et al., 2015).

3.2.1 Development of locomotion, perching, and use of 3D space

As Galliformes are primarily ground dwelling species, domestic fowl are not particularly well suited to life in complex three-dimensional spaces. However, a hen's ability to successfully navigate a complex aviary environment is not only important for finding food, water, and nest boxes, but may also influence her risk for injuries, in particular keel bone fractures which may occur from collisions with perches or other elements in the housing system (Sandilands et al., 2009). Recent work indicates that the addition of ramps in adult aviary systems significantly reduced the number of falls, collisions, and keel fractures as well as foot pad disorders (Heerkens et al., 2016; Stratmann et al., 2015). However, we currently have very little understanding of the specific locomotor skills hens require to physically navigate inclined ramps or other elements in aviary housing or how those motor skills develop (Harlander-Matauschek et al., 2015).

Access to perches early in life provides a number of benefits to laying hens, reducing the risk of feather pecking, cloacal cannibalism, and floor eggs (Gunnarsson et al., 2000; Huber-Eicher and Audigé, 1999). Despite this, there has been surprisingly little work on perch design or perch space requirements for chicks and pullets or on strain differences in perch use. Early work by Appleby and Duncan (1989) investigating the provision of perches to medium hybrids from 5 weeks of age was the first to suggest that the initiation of perching and even jumping between vertical levels involved a learning process during a sensitive phase of early development that was important for hens to later make use of elevated nest boxes and prevent floor eggs. Later, the classic study by Gunnarsson et al. (2000) demonstrated that when Hisex Brown chicks were provided access to perches from 1 day versus 8 weeks of age, they performed significantly better at 16 weeks in a test that required navigation between tiers to access a food reward; this suggested that the development of complex spatial cognitive abilities required experience with perches sometime before 8 weeks of age.

Several researchers have tracked development of perching in individual strains and generally in small groups, using a variety of perch designs (e.g., softwood rails, unspecified wood, and round metal) and heights (usually several ranging from 20 to 60 cm high). Newberry et al. (2001) found that daytime use of perches by White Leghorn chicks gradually increased from 3 to 18 weeks of age, with pullets increasingly using higher perches. From 3 to 6 weeks of age, around 28% of birds were observed perching at any one time, and between 40% and 50% from 12 to 15 weeks of age. In this study, the amount of perching depended on group size, with a greater percentage of birds perching in groups of 15 (41% of birds perching) than 120 (33% perching). Heikkilä et al. (2006) observed that Lohmann White chicks began perching during the second week of life, gradually increasing to reach 20% of birds perching at 6 weeks of age. Night-time perching developed later than daytime with less than 10% of the group observed on perches at night at 6 weeks. It should be noted that chicks in this study had to leave their heat source (heat lamp) in order to gain access to perches. Riber et al. (2007) showed that the presence of a broody hen stimulated earlier perch use in Lohmann Tradition (brown-feathered) chicks, with brooded chicks beginning daytime perching on average 3.5 days sooner than nonbrooded chicks. The onset of night-time perching was not affected by the presence of a broody hen and did not begin until around 20 days of age. The proportion of birds observed perching over time was not given, although the authors reported that all but 1 of the 120 individual chicks observed in the study (a nonbrooded chick) used a perch at some time during the 6 weeks of the study. Early work identified age and strain differences in perch use in adult hens (Faure and Jones, 1982a,b) and different strains of hens show considerable differences in distribution patterns across vertical space in aviaries (Ali et al., 2016). Jumping onto, moving between, grasping and balancing on perches requires complex cognitive and sensorimotor control (LeBlanc et al., 2016). Research aimed at investigating how and when different strains of layer pullets use vertical space is only beginning to be explored (Habinski et al., 2016; Kozak et al., 2016a).

To improve our understanding of locomotor capacity and the use of vertical space in layers, Kozak et al. (2016b) investigated how four commercial strains (LSL-Lite, HyLine Brown, Dekalb White, and Lohmann Brown) used the floor, perches, ramp, ladder, and elevated platforms in small custom aviaries from 1 to 9 weeks of age. Perches and platforms were located at several levels with both a ramp and a ladder leading to the highest level. Food and water were provided at ground level on the litter floor. Vertical space was divided into four sections: S1 ground, S2 low perch to first platform (15−69 cm), S3 in between first and second platform (70−159 cm), and S4 second platform to high perch (160 cm +). Behavioral events (walking, running, jumping, and perching) were observed during a 30-minute period each week 7 hours after the lights were turned on. During the first week, all chicks remained on the ground level. In weeks 2 and 3, 30%−40% of behavioral events (use of low perches) were observed to occur on S2, increasing thereafter. S3 was used only minimally from week 4 and behavioral activity was rarely observed on the highest level and only in week 9. Locomotion and perching was observed on the ramp and ladder from weeks 2 through 5. Lohmann LSL chicks used the space above the ground significantly more than the other strains and performed more aerial ascent than the other lines. In another recent study, day and night-time perching behavior was compared across three stains of purebred heritage breeds (Columbia Rock, Rhode Island Red, and White Leghorn) housed in a high-density commercial "Combi style" rearing cage that provided perches at three different levels as well as a platform (Habinski et al., 2016). A chain feeder was located on the floor and the nipple drinker line was adjusted for bird height as they grew. Perch use was generally low throughout the 14-week study (less than 30% of birds per group observed perching), although it gradually increased from 1 to 6 weeks

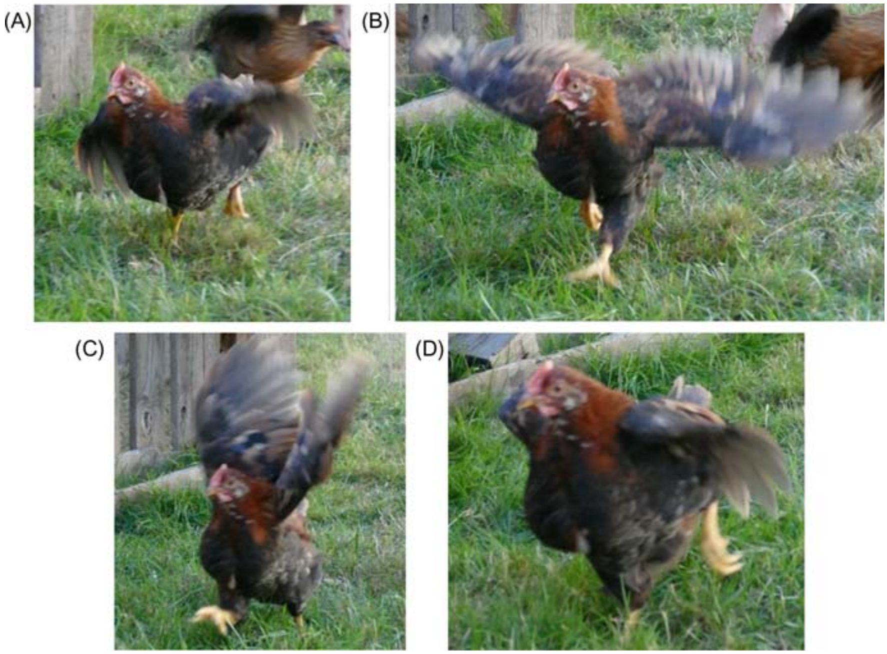

Figure 3.1 (A–D) Wing-assisted running exhibited by *Galliformes* during rapid motion and antipredator escape attempts. Example shows a 6-week-old pullet.
Source: From Casey-Trott (2016).

of age, fluctuating thereafter. Columbia Rocks used perches and the platform the most; Rhode Island Reds perched the least and rarely used the platform. On average, the growing pullets used the perches more during the day than night and the lowest perches were used the most. Interestingly, the birds perched most on sections of the perches that were in close proximity to the cage walls.

In addition to jumping onto and balancing on perches, laying hens need to develop other forms of locomotion to be able to navigate complex systems. Precocial terrestrial birds routinely use both their hind limbs and forelimbs to navigate three dimensions as they ascend to elevated surfaces. When running to escape predators and moving up inclines, wild Galliformes use a form of locomotion called "wing-assisted running" or "wing-assisted incline running" (WAIR) which involves coordinating wing flapping with hind limb movement to produce aerodynamic forces that assist in lift (Tobalske and Dial, 2007) (Fig. 3.1). A recent study investigated locomotor strategies and climbing capacity of four different strains of laying hens from 2 to 36 weeks of age on inclined ramps ranging from 0 to 70 degrees to reach tiers that were either 70 or 160 cm high (LeBlanc et al., 2017). Both chicks and adult birds used walking to climb 40 degree inclines, but when inclines became steeper, they performed more WAIR and aerial ascent (jumps and short flights). Chicks were more successful at performing WAIR than older birds, and white strains performed more WAIR than brown-feathered strains. From 8 to 36 weeks of

Figure 3.2 Testing a pullet for locomotion style and climbing capacity on an inclined ramp. *Source*: LeBlanc (2016).

age, birds increasingly performed more aerial ascent on inclines greater than 40 degrees, which was likely due to the development of their flight muscles and capacity for flight. White strains (Dekalb White and LSL-Lite) were considerably more successful at reaching both the lower and upper tiers at ramp angles of 50, 60, and 70 degrees compared to the brown strains (Lohmann Brown and Hyline Brown). Additionally, measures of peak ground reaction forces and foot contact times in anticipation of inclines of 0, 40, or 70 degrees indicated that birds between 17 and 36 weeks of age generated higher peak forces and had the longest foot contact time prior to ascending a 70 degrees incline compared to 40 degrees (LeBlanc, 2016). The author suggested that birds experienced with these steeper ramps required more time for sensory processing as they prepared to make the more difficult ascent. Overall, this work demonstrated that laying hen chicks and adults from a variety of strains can easily walk up ramps with up to 40 degree inclines, but ramps at 70 degrees are difficult, particularly for brown strains. Ramps at intermediate angles stimulated a combination of walking and WAIR. While the authors suggest that ramps of 40 degrees or less are the safest for all ages and strains of birds, there could be benefits to designing systems that encourage chicks and pullets to perform some degree of WAIR (Fig. 3.2). Increased wing-flapping during development may assist young birds in developing neuromuscular coordination as well as musculoskeletal strength (Harlander-Matauschek et al., 2015). The use of pectoral muscles during WAIR may also result in load-bearing on the keel which could affect growth, increase keel bone strength, and reduce later risk of fracture (Casey-Trott et al., 2017a).

3.2.2 Rearing effects on physical development

Although skeletal health has been at the forefront of laying hen research for decades, osteoporosis and its associated welfare problems are far from being eliminated. While mainly a consequence of selection for high egg production and the calcium stores required to support it, osteoporosis and weak bones are known to be exacerbated by restrictive housing where the opportunity for load-bearing exercise is limited. Adding perches, elevated dust baths and providing larger space allowances and opportunities for flight have all been shown to improve bone strength in adult hens, with marked improvements predominately seen where the opportunities for load-bearing exercise are substantial and diverse (Whitehead, 2004). Because osteoporosis is most often detected only during egg production, minimal research efforts have targeted the pullet rearing stage for means of prevention. In humans, osteoporosis is now considered to be a pediatric disease, as bones that do not develop adequate structural support during childhood and adolescence are especially susceptible to weakness later in life (Burrows, 2007). Current research in laying hens is also focusing on early rearing environment as a means to improve bone health.

Several recent studies have examined musculoskeletal development of pullets that were offered more opportunities for load-bearing exercise, either by providing access to perches in rearing cages (Enneking et al., 2012), rearing in an aviary from 6 weeks of age (Regmi et al., 2015), or rearing in an aviary that provides access to horizontal and vertical space from 1 day of age (Casey-Trott et al., 2017b). Pullets provided perches in conventional rearing cages had increased leg muscle deposition as well as increased bone mineral density in the sternum, tibia, and humerus at 12 weeks of age compared to pullets reared without perches (Enneking et al., 2012). Pullets reared in an aviary from 6 weeks on had increased cortical (structural bone) density and greater strength and stiffness of the tibiae and humerae compared to pullets kept in conventional cages for 12 weeks (Regmi et al., 2015). Pullets housed in an open aviary from 1 day of age had heavier breast muscle weights, larger keels, greater bone density and strength of their tibia, humerus and radius at 16 weeks compared to pullets from conventional cages (Figs. 3.3 and 3.4) (Casey-Trott et al., 2017b). Most importantly, in all three cases, positive differences in musculoskeletal characteristics between birds provided more exercise during rearing versus conventional cages persisted until end of lay, even when hens were subsequently housed in more restrictive housing for the laying period, indicating that these developmental influences had life-long effects on skeletal health of the birds (Fig. 3.4) (Casey-Trott et al., 2017c; Hester et al., 2013a,b; Regmi et al., 2015). Additionally, Casey-Trott et al. (2017a) found that aviary-reared birds had substantially fewer keel fractures than conventionally cage-reared birds, when hens from both treatments were subsequently housed in enriched colony cages. In all of these studies, providing additional opportunities for exercise during the laying phase by providing perches (Hester et al., 2013a,b), housing hens in larger enriched colony cages (Casey-Trott et al., 2017c), or housing them in aviaries (Regmi et al., 2016) allowed hens to maintain better bone characteristics during the laying phase.

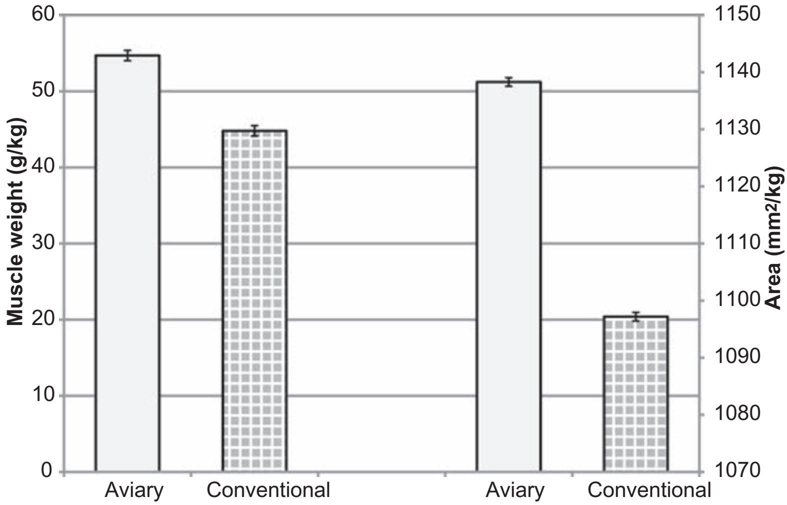

Figure 3.3 Comparison of weight of pectoralis major (g/kg body weight) and keel area (mm^2/kg body weight) of 16-week-old pullets reared in either an aviary or conventional rearing cages. The rearing aviary used for the study is the one shown in Fig. 5.7.
Source: Adapted from Casey-Trott et al. (2017b).

3.2.3 Rearing system design

The designs of noncage rearing systems for laying hens are continuously evolving and currently there are a number of different variations that are used commercially. These can basically be divided into four different styles: 1. Traditional noncage rearing comprised of litter floor pens furnished with perches, and sometimes platforms (Fig. 3.5). 2. Aviary systems that start pullets in an area similar to standard rearing cages but that are outfitted with low perches. Chicks are started in the enclosed cage (Fig. 3.6), but as they grow (usually 4−6 weeks of age), the front of the cage is opened to allow access to the barn and litter floor. 3. Aviary systems that offer more vertical space to chicks within the starting cage and include different levels of perches and platforms during the first weeks of life; again, as the birds grow these cages are opened to allow them access to the barn and litter floors (Fig. 3.6). 4. Aviary systems that provide significantly more vertical and horizontal space from 1 day of age. As chicks grow, perches and platforms within the system are raised and terraces are opened to provide access to the litter floor. These different designs of rearing systems facilitate or require different types of locomotion (e.g., running, perching, climbing, and flying) at different ages and stages of development (Fig. 3.7). Currently, little is known how these different designs when combined with different management strategies affect adaptation to adult housing.

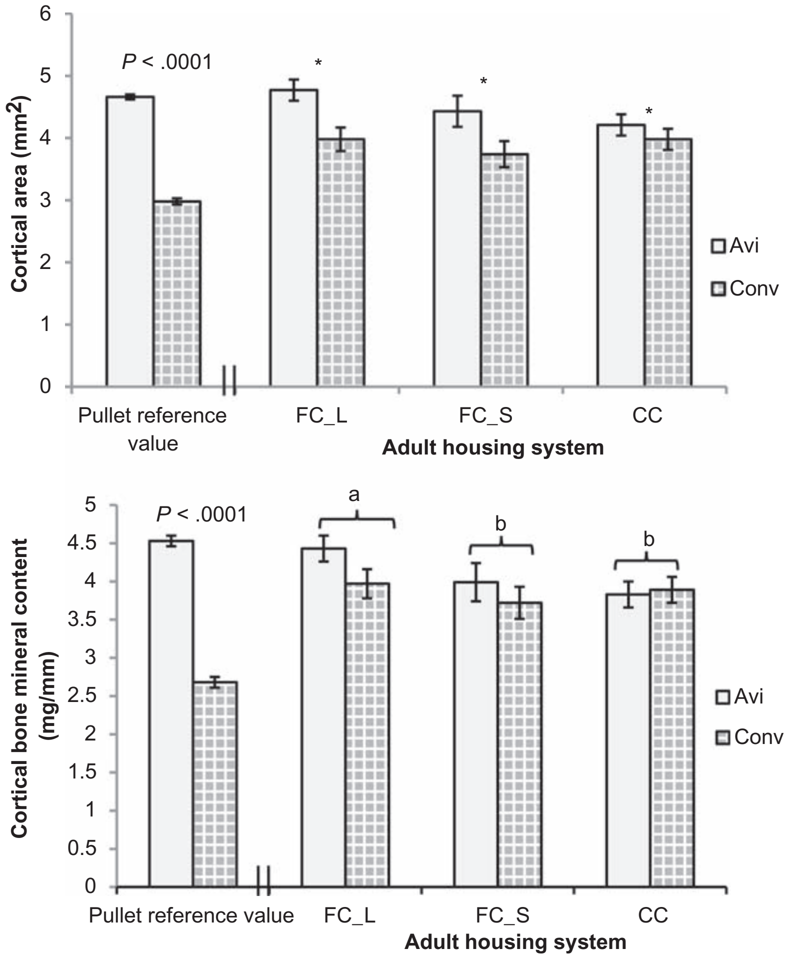

Figure 3.4 Quantitative Computed Tomography (QCT) measurements comparing the effect of aviary (Avi) versus conventional (Conv) rearing and adult housing environment on cortical (structural) bone measures of the radius at 16 weeks (Pullet reference value) and at 73 weeks from hens housed in a 60-bird furnished cage (FC-L), a 30-bird furnished cage (FC-S), and conventional cages (CC). Effects of rearing ($P < .05$) in adult bones at 73 weeks of age is designated by *. Differences ($P < .05$) among adult housing systems are designated by differing letters ab.
Source: Adapted from Casey-Trott (2016).

Surprisingly, there is only one published study to date that investigated the effect of rearing system on adaptation of pullets (ISA Brown) to aviary housing in commercial settings (Colson et al., 2008). The authors compared vertical space use, numbers and distances of flights and jumps, nest box use and mortality of pullets reared in either floor pens furnished with perches and a platform, a three-tiered

Figure 3.5 Example of a floor-rearing system for pullets in which perches and platforms have been added.
Source: Photo by Leanne Cooley.

aviary system with water nipples on the platform and feed hoppers on the litter floor, or a three-tiered aviary with chain feeders on two of the platforms. During brooding and until 29 days of age, floor-reared chicks did not have access to the platform and aviary-reared birds were restricted to the middle tier without perches. Compared to the aviary-reared pullets, those reared in the floor system showed less accuracy during flying and jumping, used lower levels most, laid more floor eggs, and had higher mortality after transfer to the aviary. The difference in aviary feeding systems had fewer effects on adaptation after transfer although the authors recommended a greater vertical distance between feed and water to force pullets to move up and down. A more recent study found that pullets reared in a commercial aviary used perches and platforms significantly more than cage-reared birds when transferred to enriched floor pens at 19 weeks, but by 23 weeks differences in spatial distribution were no longer detected (Brantsæter et al., 2016a).

Pullets with less experience may be able to adapt to some types of systems over time, but are likely to have poorer problem solving skills in addition to less neuromuscular coordination and musculoskeletal strength. Recent studies have shown

(A)
(B)

Figure 3.6 Commercial rearing aviary in which chicks are started in an enclosed furnished cage. (A) This example has several levels of perches and a platform so that chicks can perch from 1 day of age. (B) At around 6 weeks of age the cage fronts are opened to provide pullets with access to litter. Feed and water are provided on both the lower and upper banks of cages.
Source: Photos by Leanne Cooley.

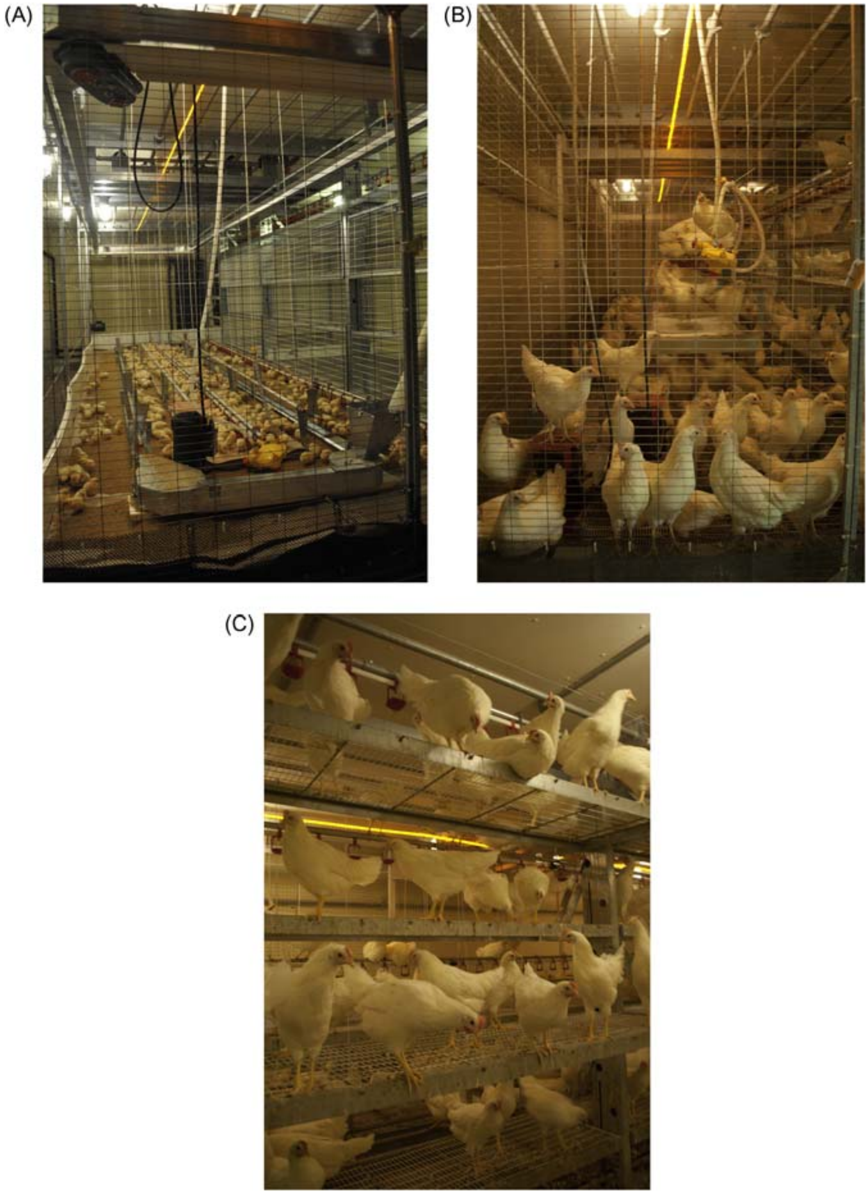

Figure 3.7 Commercial rearing aviary for pullets that provides opportunities for running, perching and flying from 1 day of age. (A) Chicks are started in the large enclosed system where feed and water are provided. (B) As the pullets grow, platforms, water lines, and perches are raised and (C) terraces are opened (usually around 6 weeks of age) to allow birds access to a litter area (not shown).
Source: Photos by Michelle Hunniford.

that, compared to pullets reared in conventional rearing cages, those reared in aviaries have better working memory as well as increased ability to perform spatial tasks (Tahamtani et al., 2015).

3.2.4 Rearing effects on fearfulness

Fearfulness is of particular concern in noncage and free-range systems as prolonged fear directly impacts welfare and increases risk for panic, smothering and injuries. In free-range flocks, individual hens that prefer to remain indoors show greater responses, or at least different types of responses, when tested for fearfulness (Campbell et al., 2016; Hartcher et al., 2016). Fearfulness is determined by genetic predisposition as well as experience (Campo et al., 2014; Rodenburg et al., 2008). Birds that show fearful responses as chicks also have higher corticosterone levels as adults, but the presence of fearful birds in a group can affect other birds' sensitivity to stress (de Haas et al., 2012). Furthermore, when birds from more docile and less fearful genetic lines were reared with birds from a line that were more fearful and flighty, the more docile line showed signs of increased fear as adults (Uitdehaag et al., 2009).

Environmental enrichment and human handling early in life (Jones, 1996) as well as rearing with a broody hen (Campo et al., 2014; Rodenburg et al., 2008) reduced fearfulness in laying hens. Compared to hens reared in standard cages, hens reared in aviaries showed less fear in novel object tests when tested in pens (Brantsæter et al., 2016a) and furnished cages (Brantsæter et al., 2016b; Prinold and Widowski, unpublished data; Tahamtani et al., 2014). However, when comparing responses to initial exposure to novel objects at 19 weeks of age, aviary-reared hens also showed a more active response (flying up) than cage-reared hens, although this difference was no longer observed by 23 weeks (Brantsæter et al., 2016b). Interestingly, outbreaks of panic in free-range flocks are observed most in younger flocks (Richards et al., 2012). Research into practical means for reducing fearfulness and managing responses to fearful events of pullets reared in noncage systems is warranted.

3.2.5 Prenatal developmental effects

In addition to postnatal experience and genetics, a hen's behavior can be altered through prenatal exposure to nutrients or hormones in the egg (Dixon et al., 2016) and by epigenetic mechanisms (Jensen, 2014). Epigenetics broadly refers to the transgenerational transfer of phenotypic characters without modification of gene sequence through chemical modifications of DNA that alter gene expression patterns (Jensen, 2014). Environmental challenges or stressors experienced by a mother can affect the general development of her offspring; they can impair growth and stress-axis activity and affect fearfulness, cognitive abilities, and social behavior. In birds, one mechanism for this is the alteration of maternal hormone profiles and subsequent changes in concentrations of steroid hormones in the yolk (Breuner, 2008). The effects may be transient, only lasting the lifetime of the offspring, or they may affect the germ-line, resulting in the alterations in gene expression that are passed down to subsequent generations (Nätt et al., 2012). In wild species there is considerable debate as to whether this "fetal programming" has deleterious consequences on offspring or whether it confers an adaptive advantage by matching offspring to a harsh (or hospitable) maternal environment (Breuner, 2008). In either case, the consequences of maternal effects on behavioral phenotype are highly relevant in a production environment.

The effects of various types of maternal stress on egg and offspring characteristics as well as on gene expression have been demonstrated in a number of studies conducted on quail, red jungle fowl (RJF), and domestic fowl (see reviews by Dixon et al., 2016; Jensen, 2014; Rodenburg, 2014). In quail, for example, unpredictable fearful stimuli and social instability affected egg traits (weights, composition, and yolk androgen levels) and offspring growth rates and reactivity to standardized tests for fear. In ovo treatment of eggs with corticosterone reduced growth rates, increased avoidance of humans, and reduced ability to compete for a food reward in the chicks (Janczak et al., 2006). When laying hens were subjected to unpredictable feed deprivation, their offspring had a longer duration of tonic immobility and spent less time eating in a competitive feeding test. In response to various stressors, both Lindqvist et al. (2007) and Nätt et al. (2009) found differences in gene expression in the brain that corresponded to behavioral differences found in the offspring of stressed parents.

The degree to which a hen transfers epigenetic information to her offspring may depend on her genotype. Comparisons between RJF and White Leghorns (WL) indicate substantial breed differences in gene expression and methylation profiles in the brains of both parents and their offspring (Nätt et al., 2012). When stressors were imposed on both RJF and WL parents, only the offspring of WL showed reductions in learning, differences in feeding behavior and differential gene expression in the hypothalamus and pituitary, indicating a higher susceptibility to epigenetic effects in the domesticated/highly selected bird (Lindqvist et al., 2007). When comparing the fearfulness of chicks derived from brown and white hybrid commercial breeder flocks, de Haas et al. (2014) recently found that white hybrid chicks were more sensitive to the effects of parental stress than were brown hybrid chicks. Age of the mother may also affect susceptibility to stress, with subsequent effects on growth, development, and fearfulness of her chicks. In quail, age of parents was shown to affect yolk testosterone levels, offspring growth rate, and sexual maturation as well as responses to fear and novelty in quail chicks (Guibert et al., 2012). Our preliminary results indicated a significant effect of maternal age on vocal responses of 5-day-old chicks to social isolation using the chick anxiety–depression model test (Cooley et al., 2016).

From a practical perspective, this body of work suggests that the experiences of the parent (breeder) flock of layers may differentially affect the behavior of their daughters, depending on genotype and parental age. This could help explain why we often observe significant flock to flock variation in birds of the same strain receiving similar housing and management. This is an area that necessitates significant research activity.

3.2.6 Rearing systems for furnished cages

While it is clear that rearing in enriched systems has beneficial effects on behavior and physical condition of laying hens, there are questions concerning optimal rearing environment for hens destined for furnished cages. To date, few designs of furnished cages have been developed for chicks and pullets, and for economic reasons it may be more practical to rear them in noncage systems. The majority of furnished cage flocks reported in Sherwin et al. (2010), for example, were reared in floor systems. However, the welfare implications of noncage rearing of pullets destined for furnished cages, where space and freedom of movement are more constrained, have been questioned (Janczak and Riber, 2015).

Tahamtani et al. (2014) observed that hens reared in aviaries exhibited more alert and comfort behavior than hens reared in standard cages when transferred to small furnished cages housing 7−9 birds, but had higher mortality. They concluded that hens reared in aviaries were better able to cope with environmental change but that long-term welfare might be compromised when moving from a large complex environment to a small furnished cage. However, the effects of rearing may be different for hens destined for larger furnished cages (referred to as enriched colony systems), where total space allowance, group size, and social structure are different. We recently completed a 4-year longitudinal study on the effects of rearing pullets in a complex aviary system versus conventional rearing cages using four flocks of birds. When subsequently housed in large (30- or 60-bird) furnished cages, hens reared in aviaries showed reduced fearfulness (e.g., lower latency to approach a novel object) than cage-reared hens but there were no treatment differences in fecal corticosterone levels during the first few days or weeks following transition to cages (Prinold and Widowski, unpublished data). Body weights of hens reared in aviaries were the same as those reared in cages at the beginning of lay but aviary-reared hens were significantly heavier at 72 weeks. Over the entire laying period there were no rearing differences in hen-day egg production, feather condition, or mortality, and several measures of foot health were improved by aviary rearing (Widowski et al., 2017). As previously mentioned, analysis of bones excised from hens at end-of-lay using quantitative computed tomography indicated that hens reared in the aviary had significantly greater area and bone mineral content of structural bone in the radius, humerus, and tibia (Casey-Trott et al., 2017c) as well as fewer keel fractures (Casey-Trott et al., 2017a) compared to pullets reared in standard cages. Behavioral studies indicated that rearing experience affected hens' perceptions of the furnishings in the cages but these effects did not appear to be adverse. For example, aviary-reared birds laid more eggs in the scratch area versus the nest, but their pre-laying behavior was actually more settled than that of hens reared in cages (Hunniford and Widowski, 2016). Aviary-reared birds, however, did use perches more in the daytime than cage-reared hens (Casey-Trott and Widowski, 2016). Overall, these results suggest no detrimental effects and several beneficial effects of rearing in a complex environment on the well-being of hens subsequently reared in large furnished cages.

3.3 Welfare related to feeding the modern chicken and turkey

Chickens and turkeys are precocial species at hatch, mobile and able to eat independently. However, they require assistance during the first couple of weeks of life in finding food sources. In the wild, chicken and turkey hens assist their offspring in locating appropriate feed through visual (Gentle, 1985; Stokes, 1971) and auditory cues (Bate, 1992; Woodcock et al., 2004). With the advent of modern agricultural practices that include the rearing of chicks and poults separate from their dams, the modern domestic fowl must learn to eat and drink alongside equally naïve conspecifics. As a result, young broiler chicks and turkey poults are susceptible to starvation and dehydration during the first week of life. There has been significant work over the past couple of decades on improving nutrient specifications to aid early development (Noy and Uni, 2010; Sklan, 2001). Yet, there remains the challenge of both getting birds to eat (particularly during the first couple of days posthatch) and getting other birds to stop eating (as is the case for breeder birds that must be feed restricted). Below, we will discuss novel research on factors influencing the development of early feeding behavior including *in ovo* feeding and early access to feed through combined hatching and brooding systems. We will then discuss feed restriction for broiler breeders. Due to genetic selection for fast growth, broiler breeders have the potential for such fast growth that it would lead to metabolic and fertility problems. As a result, they are routinely feed restricted, leading to behavioral and physiological signs of chronic hunger. New strategies for examining the effect of alternative feeding strategies on breeder welfare will be discussed.

3.3.1 Novel early feeding methods

With modern chicken strains reaching market weight by 6 weeks of age, a third of the chicken's life is spent *in ovo*. Incredible metabolic and physiological changes occur within the embryo during the last week of development, including significant development of the gastrointestinal tract (Lilburn and Loeffler, 2015). This development continues posthatch in concert with improvements in immunocompetency (Panda et al., 2015), but is delayed when chicks experience a posthatch fast (Uni and Yahav, 2010). There is often upward of 24 hours from the first hatched chicks to the last (Careghi et al., 2005), and this hatch window is often followed by periods of up to 24 hours before placement at the farm (Wang et al., 2014). This extended period from hatch to placement may pose a problem when chicks encounter challenges, particularly if commercial production is moving toward removing prophylactic antibiotics from feed. In standard practice, approximately 5% of placed broiler chickens die within the first week of life, often due to low energy reserves or inability to battle disease challenges. Under drug-free production, this mortality rate can double (Sun et al., 2005). To assist the gastrointestinal development of the chick, a group at North Carolina State University and Hebrew University of Jerusalem developed a method to feed the chick *in ovo* via administration of exogenous nutrients into the amnion during late embryonic development (Uni and Ferket, 2004). They performed a series of experiments examining the effect of *in ovo* feeding of carbohydrates and amino acid metabolites on both chick and poult growth rates (Foye et al., 2007; Tako et al., 2004; Uni et al., 2005) and found that the method improved gastrointestinal development and increased hatch and 7-day weights compared to control treatments. Kornasio et al. (2011) compared the effects of *in ovo* feeding to early feeding (within 6 hours) posthatch on growth rates and gastrointestinal development in broiler chicks. Both *in ovo* and early feeding increased body weights to day 35 and aided early gastrointestinal development compared to standard practice, although only the early fed chicks (with or without *in ovo* feeding) did not lose weight during the first 2 days after placement on farm (Kornasio et al., 2011). As *in ovo* feeding is still a new technology, the full impact of this early feeding method on chick and poult welfare, particularly when the chicks or poults are challenged with diseases, is yet unknown.

As mentioned earlier, chicks and poults are often fasted for extended periods between hatch and placement due to logistics, and this fast can reduce growth rates (Kornasio et al., 2011; Zulkifli et al., 2016), delay gastrointestinal development (Bigot et al., 2003), and slow development of gut associated lymphoid tissue, which can leave neonates particularly vulnerable to disease challenges (Shira et al., 2005). We recently found that early hatched turkey poults, hatched and reared under normal commercial conditions, had a higher prevalence of mortality due to air sacculitis compared to a standard hatch control group (Roehrig and Torrey, unpublished), potentially indicating greater susceptibility to bacterial infections with increasing time between hatch and first feed. Different techniques for increasing early feed intake to improve welfare have been developed, including early nutritional supplements and combined hatching and brooding systems.

van den Brand et al. (2010) studied the effect of early feeding with dextrose, albumen, prestarter, or a prestarter with fat on thermoregulatory development in broiler chickens. Early feeding with the prestarter, probably due to the increased dietary complexity, increased early body weight gains and intestinal length, and aided chicks' resistance to cold temperatures through 3 days of age. Other nutritional supplements have also been found to increase early intestinal development (Suzuki et al., 2008) and improve response to disease challenges such as coccidiosis (Dibner et al., 1998).

To reduce the time between hatch and first feed, Kuijpers et al. (2002) developed an innovative system for combined hatching and brooding. This system, now commercially available from a number of companies, involves hatching chicks on farm so they have immediate access to feed and water. To date, most of the research on these combined hatching and brooding systems has focused on growth rates (Van de Ven et al., 2009, 2011, 2013). Compared to conventionally hatched chicks, those hatched into brooding systems were heavier at hatch (de Jong et al., 2016; Van de Ven et al., 2009, 2011), and had lower plasma corticosterone and glucose concentrations (Van de Ven et al., 2011, 2013). These physiological differences may indicate differences in stress susceptibility, or could be due to metabolic changes occurring due to the fasting period. In the first experiment to examine behavioral parameters with regard to this new rearing method, de Jong et al. (2016) studied the differences between standard hatched chicks and those hatched on farm. They found that the standard hatched chicks performed more vocalizations in a novel environment soon after placement on farm, but these differences were no longer apparent at day 21. There were no differences in lameness despite standard hatched chicks having worse litter condition and a higher prevalence of foot pad dermatitis, although standard hatched chicks had higher mortality rates (de Jong et al., 2016). As this was the first study to include welfare parameters, additional studies of the immediate and long-term implications of this novel environment on chick welfare are warranted.

3.3.2 Feed restriction practices

Modern commercial strains of broiler breeders have similar genetic potential for fast growth as their broiler offspring. However, in order to limit problems, such as obesity, lameness, and ascites, and maintain adequate reproductive capabilities, broiler breeders are feed restricted throughout their production, most severely during the rearing phase where they receive about 45% of the feed allotment that a similar weight broiler receives. As a result, they often exhibit signs of chronic hunger, including object and feather pecking, excessive drinking, and a high motivation to feed, even immediately after consuming their daily ration. Over the past 15 years, much research has focused on the use of alternative feed ingredients to improve breeder welfare (e.g., Morrissey et al., 2014; Nielsen et al., 2011; Sandilands et al., 2005; Savory and Lariviere, 2000). Experimentally, the combination of fibrous ingredients (particularly oat or soybean hulls) and increasing levels of calcium propionate (as an appetite suppressant) supplemented in the diet during rearing has been studied (Sandilands et al., 2006), and found to control growth rates, maintain weight uniformity, and reduce behavioral indicators of hunger both during the period of peak restriction and into the lay period (Morrissey et al., 2014; Sandilands et al., 2005; Tolkamp et al., 2005).

Recently, more attention has been paid to the welfare implications of nondaily feeding schedules. In North America, broiler breeder restriction is typically managed through nondaily feeding schedules, such as skip-a-day feeding, where birds receive twice their daily allocation every other day, because of the purported success of these programs in improving flock uniformity. Yet, the practice of nondaily feeding is banned in some countries because of the perceived insult to welfare (DEFRA, 2007). We have recently begun studying the effect of nondaily feeding schedules, in conjunction with alternative diets, on breeder welfare both during rearing and into lay. Compared to daily fed birds, birds fed on nondaily feeding schedules during rearing had significantly improved feather condition (Morrissey et al., 2014; Mosco et al., 2016), and similar motivation for compensatory feed intake (Arrazola et al., 2016), although they had worse feed efficiency (Arrazola et al., 2016; Lostracco et al., 2014). These results suggest that, for quantitative restriction programs, nondaily feeding is not worse for broiler breeders' welfare than daily feeding. We are analyzing whether the experiences of breeder pullets reared on different feeding schedules carried over into production or into the next generation.

In addition, broiler breeder feed restriction practices may have broader implications than just during the breeders' rearing or production periods. Metabolic changes in parent stock resulting from different feeding frequencies (Ekmay et al., 2010; Janczak et al., 2007) or diet densities (Enting et al., 2007; Leandro et al., 2011) have transgenerational impacts on progeny growth and metabolism, possibly through epigenetic mechanisms (Ford and Long, 2011). Stressing hens through unpredictable lighting schedules resulted in altered gene expression in the hens that was transmitted to their progeny (Lindqvist et al., 2007). In sheep, maternal nutrition influenced energy and nutrient allocation through two generations, with undernutrition leading to the development of a "thrifty phenotype" predisposed to obesity and metabolic diseases (Ford and Long, 2011; George et al., 2012). Feed restriction of broiler breeders during lay altered their hepatic lipogenic gene expression (Richards et al., 2003), and unpredictability in laying hens' access to feed changed their behavior and gene expression in addition to that of their progeny (Lindqvist et al., 2007; Nätt et al., 2009). Since different feeding strategies differentially affect the behavior and productivity of broiler breeders, there may be heritable changes in gene expression occurring as well. New technologies in assessing epigenetic gene expression should be harnessed to better understand the full effects of feed restriction practices.

3.4 Rearing for social adaptability

In natural or semi-natural conditions, chickens and turkeys live in defined social groups. During rearing, chicks and poults group together with their hen and other adult hens, and use auditory and visual stimuli to learn social behavior from their hens and siblings (Wood-Gush, 1955). They begin forming peck orders within the first few weeks after hatch through threats and overt aggression (Guhl, 1958). Within small, established groups, hierarchies remain stable, with birds using physical cues such as body size and comb characteristics to recognize conspecifics (Candland, 1969). However, modern commercial housing conditions differ significantly from natural or semi-natural conditions, with broiler chickens and turkeys often reared in single sex groups of hundreds or thousands of same-age conspecifics. Layer pullet rearing environments are much more variable, although increasing numbers of pullets are being reared in large free-run pens. To date, however, there is little known about the effect of early social experiences on birds' adaptability into adulthood, particularly for turkeys and broiler breeders.

With group sizes increasing, more emphasis is being put on understanding social dynamics and spatial distribution of birds, particularly to minimize the development of harmful behavior such as feather pecking and aggression. Researchers have found that chickens prefer to be closer to birds with which they had been reared (Lindberg and Nicol, 1996), although group size influenced aggression, as unfamiliarity within small groupings led to more aggression than within larger groupings (D'Eath and Keeling, 2003). In small groups, familiar turkeys flocked together more than unfamiliar turkeys (Buchwalder and Huber-Eicher, 2003), although it is unclear if such affiliative behavior would hold true in very large groups. D'Eath and Keeling (2003) suggested that birds in large groups (in their case, 120 birds) are unable to recognize individual flockmates, unlike those in groups of 10 birds. Estevez et al. (2003) tested the hypothesis that birds are able to establish a dominance hierarchy in small groups, but develop a tolerance strategy in large groups. They reared White Leghorn (WL) laying pullets in groups of 15, 30, 60, or 120 at a constant stocking density and observed the development of pecks and threats given and received by focal birds. As expected, there was a linear reduction in pecks and threats given with increasing group size. In converse, pecks and threats received increased linearly with increasing group size. The authors suggested that in large groups, the majority of birds adopt a tolerance social strategy which results in an overall decrease in aggression given. However, a minority of "despotic" birds, perhaps assessing their chances of winning fights to be high, perform pecks and threats indiscriminately. Research is needed to determine if rearing in any particular group sizes better aids birds' adaptability to different group sizes in adulthood.

While broiler chickens are often placed into the barns within which they will spend their short life, broiler breeders, turkeys, and laying hens are typically transferred to new environments and social groups at least once during their life, either around 4−6 weeks of age (for turkeys), or prior to lay (for breeders and layers). Modern strains of adult laying hens respond to social group instability with more aggression than before mixing, and more than RJF (Väisänen et al., 2005), and pullets responded to repeated mixing (12 times in 15 days) in small groups with increased feather pecking (Riedstra and Groothuis, 2002). To our knowledge, the effect of social instability during rearing in large groups has not yet been explored. Research is also lacking on the impact of early experience with specific group sizes on the development of social strategies. While traditional analysis of social behavior in very large groups is difficult, novel applications of traditional tracking technology may facilitate longitudinal research on social behavior in commercial housing (Collins, 2008; Dawkins et al., 2009; Siegford et al., 2016).

Significant changes in genetics over the past 40 years have also affected the development of social behavior. Modern breeds of chickens and turkeys have been genetically selected for productivity and this selection process has changed their social behavior. Schütz and Jensen (2001) compared the behavioral strategies of RJF to two domesticated breeds (Swedish bantam and HyLine white layer pullets) during rearing with outdoor access. While the white layer pullets have been selected for increased egg production, neither of the other breeds had undergone selection for any production traits. The white layers were more inactive and less social than the other two breeds. The authors suggested that the selection for increased productivity decreased energy-demanding behavior such as social behavior due to correlated selection responses (Schütz and Jensen, 2001). Väisänen and Jensen (2003) also found differences in social behavior between RJF and WL as early as 4 weeks of age, which may indicate a genetic role in adaptability to changes in social environments during the rearing period. Turner (2011) discussed the mismatch between current genetics and housing environments, leading to the expression of harmful social behavior. New technology in genome-wide selection and advances in traditional genetic selection methods, including the incorporation of indirect genetic effects (Peeters et al., 2012), may help select animals that are adaptable to changing housing conditions, although the identification of phenotypes associated with positive social behavior is a necessary first step.

3.5 Conclusions

The early experiences of chicks, pullets, poults, and young turkeys have long-term effects on their behavior, physiology, and ultimately, welfare. While some birds like broiler chickens are only in production for a short period, others are kept in production for a year or longer, which necessitates their adaptability to changing housing, management, and social environments. Although the rearing period has been largely overlooked, early experiences with environmental complexity can help prepare laying hens physically, cognitively, and behaviorally, for stressors later in life, improving locomotion and bone health and reducing fearfulness. Turkeys, broilers, and broiler breeders have more homogeneous housing environments than laying hens, but early experiences in feeding behavior and varying social settings impact aggression, stereotypic behavior, and mortality. Events that occur even prior to a bird hatching can significantly impact their behavior and welfare as well. Emerging research is implicating a hen's early experiences, such as housing type or feed restriction strategy, on the behavior and welfare of her offspring through perinatal exposure and epigenetic effects. Increasing attention should be paid to these early experiences utilizing novel technologies to improve the welfare of poultry species.

3.6 Implications

- Research and development are needed to design pullet rearing systems for laying hens that maximize opportunities for exercise to promote musculoskeletal development and neuromuscular coordination.
- More attention should be paid as to how handling and feeding of breeding flocks influences their behavioral and physiological development, and that of their offspring.
- To reduce stress to and increase robustness of the neonate, novel technologies and new applications of existing methodologies should be studied and adopted to facilitate early feeding and social behavior

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Electrical stunning of poultry

4

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4.1 Introduction

Prior to the 20th century, animals were frequently bled at slaughter without any form of preliminary stunning. Thereafter, several different stunning methods were developed and improvements achieved. In the European Union (EU), electrical stunning for animals was introduced in an attempt to induce unconsciousness immediately prior to cutting and bleeding in order to safeguard animal welfare, or to immobilize the animal to facilitate automatic neck cutting, as in the United States. Electrical water bath stunning of poultry has long been the common method used in Europe. This water bath method is based on the application of an electrical current through the body of the bird, which is suspended by the legs, head-downward, in moving shackles. EU legislation demands that there is always sufficient current to ensure an effective stun that continues until the bird is dead. A stun is deemed effective if it renders the bird rapidly (<1 second) unconscious and insensible for a period of at least 45 seconds. The aim of any stunning system has to be to achieve a 100% effective stun (EFSA, 2012).

According to the European Council Directive 1099 (2009) on the protection of animals at the time of slaughter:

> . . .horses, ruminants, pigs, rabbits and poultry brought into abattoirs for slaughter shall be a) moved and if necessary placed in lairage, b) restrained and c) stunned before slaughter. Animals must be restrained in an appropriate manner, so as to spare them any avoidable pain, suffering, agitation, injury or contusions.

Animals must not be suspended before stunning or killing. However, poultry and rabbits may be suspended before stunning provided that appropriate measures are taken to ensure that they are in a sufficiently relaxed state for stunning. Permitted methods for stunning are (1) captive bolt pistol, (2) concussion, (3) electronarcosis, and (4) exposure to special gas mixtures.

Special requirements are mentioned for electrical stunning of poultry which are also mentioned in the World Animal Health Organisation Terrestrial Animal Health Code (OIE, 2011):

In general:

- Poultry electrically stunned in a water bath should be shackled. A concern is the inversion stress and compression on leg bones.
- Poultry head-only electrically stunned should be placed in a cone. A concern is the inversion stress.
- Animal handlers should be competent.

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Bleeding:

- Birds stunned with a reversible method should be bled without delay, however, within a maximum of 20 seconds.
- Bleeding is performed by incising both carotid arteries, or the vessels from which they arise (e.g. chest stick). However, when cardiac arrest is induced, the incision of all of these vessels is not necessary.
- The staff should be able to observe, inspect, and access the birds throughout the bleeding period.
- Any bird showing signs of recovering consciousness should be re-stunned.
- No scalding carcass treatment or dressing procedures should be performed until all brain-stem reflexes have ceased.

Stunning of animals is applied to induce a state of unconsciousness and insensibility of sufficient duration to ensure that the animal does not recover before death occurs via exsanguination. Additionally, stunning should immobilize the animals to facilitate safe shackling, hoisting, and exsanguination.

Generally speaking, unconsciousness should be induced as soon as possible without imposing a detrimental effect on the welfare of the animal and meat quality. Before application of any stunning method, it is necessary to confine or restrain the animal and to position it for stunning. The effectiveness of any preslaughter stunning method can be seriously impaired by improper use of the restraining device on the animal, resulting in preslaughter stress. Concerns associated with electrical (water bath) stunning of poultry include shackling in an inverted position, prestunning shocks, insufficient submergence in the water, or inaccurate placement of the electrodes, and untimely return to consciousness before or during cutting and exsanguination.

This chapter provides a description of the electrical stunning methods available, the restraint methods required, and the general principles of electrical stunning. It also considers the possible consequences for meat quality and certain ethical issues.

4.2 Restraint prior to slaughter

4.2.1 Conventional shackling

A large proportion of the stunning, killing, and slaughter process is automatic. However, transfer of the birds from the transport crates to the shackles is still a manual exercise. This physically demanding exercise involves hanging the birds by the feet in shackles. Live, struggling birds of 2–3 kg are lifted from waist to shoulder height by the slaughterhouse personnel on to a moving shackle line which conveys them through the water bath stunner (Kettlewell and Hallworth, 1990) (Fig. 4.1).

It has long been recognized that the practice of hanging live birds upside down in shackles prior to stunning causes unnecessary pain and suffering (Sparrey and Kettlewell, 1994). There are also undesirable and stressful aspects of other handling practices with poultry that result in physical injury, mortalities, and downgrading of

Figure 4.1 Water bath stunner.

carcasses (Knowles and Broom, 1990; Nicol and Scott, 1990). Shackling is considered to be a traumatic experience for broilers, the effect of which is dependent upon the duration of shackling; however, a time lapse between shackling and stunning is unavoidable (Bedanova et al., 2007). It has been suggested that an optimum shackling period is between 12 and 60 seconds in order to reduce the risk of a major stress response in broilers, with adverse consequences for meat quality. According to Sparrey and Kettlewell (1994), the average time between hanging and slaughter ranges from 3 minutes (for broilers) to 6 minutes (for turkeys).

European Council Regulation 1099/2009 (2009) on the protection of animals at the time of slaughter or killing demands that poultry are sufficiently relaxed in the shackles to facilitate an effective stun. This would imply that the time lapse between hanging and stunning should be sufficient to allow wing flapping to cease, which Gregory and Bell (1987) suggested required a period of not less than 12 seconds between shackling and stunning.

Restraint and handling of birds requires attention to the following aspects:

- No sharp bends or steep gradients in the shackle line that is as short as possible.
- Birds are calm by the time they reach the water bath.
- A breast comforter/support is used to reduce wing flapping and calm birds.
- Birds do not receive prestun electric shocks.
- Birds are suspended in shackles by both legs.
- Birds with dislocated or broken legs or wings are humanely killed rather than shackled.
- The duration between shackling and stunning is kept to the minimum but should not exceed 1 minute.

Table 4.1 Time available to shackle birds measured for 7 and 6 hangers at different line speeds

Line speed		Time (s) available per bird	
Birds/h	**Birds/s**	**7 hangers**	**6 hangers**
6000	1.7	4.2	3.6
8000	2.2	3.2	2.7
10,000	2.8	2.5	2.2
12,000	3.3	2.1	1.8

Source: Adapted from Sparrey and Kettlewell (1994).

Inversion at shackling has been shown to result in elevated blood plasma corticosterone concentrations (Kannan and Mench, 1996), which are considered to be a useful indicator of stress in birds (McFarlane and Curtis, 1986). Other studies have indicated that duration of shackling can significantly elevate concentrations of plasma corticosterone (Korte et al., 1997). Kannan and Mench (1997) also discovered that the highest concentrations of corticosterone were found immediately after handling. If the shackles are not of the correct size, or if the line is moving too fast, birds may be forced into the shackles, causing pain. This is considered unacceptable (Wotton and Wilkins, 2004). There is neither legislation nor any recommendations concerning maximum line speed, but line speed will obviously affect the time that is available to hangers to shackle each bird (Table 4.1).

It is advisable that manual shackling of heavy turkeys (>8 kg), geese, and birds with joint deformities should be avoided. Shackles differ in design and construction. However, adjustable shackles are not considered to be an option, because the weight remains the problem (Wotton and Wilkins, 2004).

A study of shackling examined the incidences of physical damage in different batches of birds prior to and directly after shackling. For spent hens, approximately 31.4% of the hens in the first batch displayed freshly broken bones prior to shackling. In the second batch, 45.3% displayed broken bones (keel, ischium, furculum [clavicles], and femur) after shackling. Within the sample of 3115 hens, 29% displayed broken bones before stunning, of which 10%−50% could be related to handling on-farm. Approximately 3% of the live broilers sampled prior to entering the stunner had broken bones. Furthermore, 4.5% of the 132 birds had dislocations of the femur (presumed to be catching damage). Thumb-sized bruising on thighs was observed that was thought to be caused by shackling (Gregory and Wilkins, 1989, 1990). Incidences of red wing tips (Gregory et al., 1989) were also observed and were considered to be potentially associated with shackling.

4.2.2 Alternative shackling devices

Lines and others (Lines et al., 2011a,b) have investigated an alternative model with a conveyor belt under the shackle line devised as horizontal breast support for the inverted birds, with their legs extended behind them in shackles. The birds are transported with breast support from the moment of shackling to the moment of entry into the water bath. At the moment of entry into the water bath the birds are swept into the water bath with their heads directly submerged under the water. This specially designed breast support conveyor effectively reduced the amount of struggling birds and improved the entry to the water bath, resulting in fewer incidences of prestunning shocks. Incidences of wing flapping are also decreased. Although initial results were encouraging, several modifications of design (avoidance of corners in shackle line; slight inclination of conveyor belt) and construction (raising conveyor belt to allow more support without allowing birds to extract their legs from the shackles) of the conveyor belt still have to be addressed.

Support of the breast appears to be a practical concept that has the potential to improve bird welfare on the shackle line. Experiments comparing a cone-shaped restrainer with standing and shackling have also been performed (Hillebrand et al., 1996). Use of the cone restrainer in combination with captive bolt stunning had a positive influence on meat quality, resulting in significantly ($P < .01$) less hemorrhaging of breast and thigh muscles compared with whole-body electrical stunning of birds in shackles. Birds slaughtered using the cone restrainer and captive bolt also displayed levels of hemorrhaging similar to those seen when using a cone and a head-only electrical stunner. Fewer broilers displayed convulsions while unconscious after head-only electrical stunning when restrained in a cone than after captive bolt stunning. Hillebrand et al. (1996) concluded that restraining broilers in a cone during stunning and exsanguination limits convulsions, making this, in their view, more esthetically acceptable. However, this design still involves inversion and the authors did not comment further on the welfare aspects of this restraining method, other than to speculate that the reduction in hemorrhaging is probably related to fewer convulsions.

A fully automated conveyor system (Fig. 4.2) has been devised by technicians at the Silsoe Research Institute in the United Kingdom in association with researchers at Bristol University, United Kingdom (Tinker et al., 2005). This system aims to eliminate all contact with humans while handling birds carefully and eliminating the need to shackle live birds. The birds are automatically shackled after separate stunning and fibrillating currents have been applied through head-only electrodes into which the birds' heads are gently lifted and restrained. It remains unclear whether this system has been developed further, although the patent has expired.

4.3 General principles of electrical stunning

4.3.1 Electro-anesthesia

Electrical stunning is based on the induction of a general epileptiform insult (grand mal or seizure-like state) in reaction to the flow of an electrical current through the brain. It is important that an adequate voltage is used to force sufficient current through the animal. This stimulation of the brain causes the equivalent of a

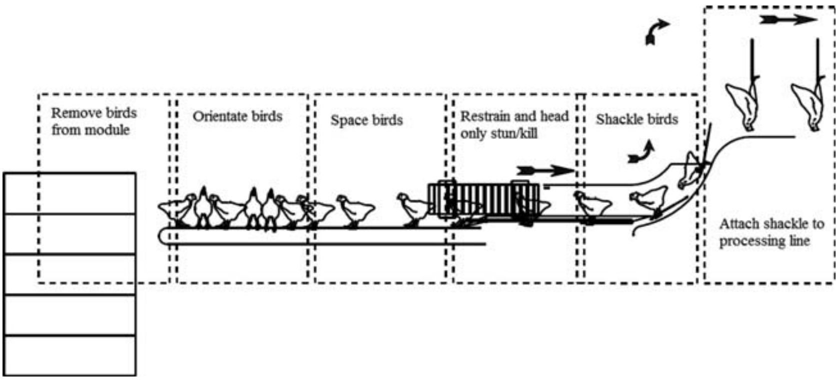

Figure 4.2 Diagram of conveyor belt system for handling birds prestunning.
Source: Tinker et al. (2005).

generalized epileptiform brain activity (meaning that all parts of the brain are stimulated) accompanied by seizures indicative of unconsciousness and insensibility. The epileptic process is characterized by rapid and extreme depolarization of the membrane potential and there is heterogeneity of findings in the configuration of the waves. As measured on an EEG (electroencephalogram) in pigs, sheep, and calves such an insult consists of relatively small waves increasing in amplitude in the tonic phase, and decreasing in frequency in the subsequent clonic phase, to result ultimately in a period of strong depression of electrical activity. In poultry, the general epileptiform insult on the EEG is characterized by a tonic/clonic phase and an exhaustion phase (Fig. 4.3). The duration of the insults differs between species and types of poultry. A minimum current, which is a function of the electrical impedance of the body, is necessary for the occurrence of such an insult.

The first phase induced by the stun produces the tonic reaction through the release of the excitatory neurotransmitter glutamate in the brain. This is followed by the release of GABA (gamma amino-4-butyric acid), which provides a period of analgesia and also assists in the animal's recovery if it is not slaughtered. The general epileptiform insult is initially characterized by a phase of tonic muscle spasms consisting of continued muscular contractions. This is followed by a phase of clonic muscle spasms comprised of a series of alternating muscular contractions and relaxations that culminate in an exhaustion phase with muscle flaccidity. During this period of initial response to the stun an eye-reflex is a useless indicator of insensibility, because this reflex is blocked during the tonic phase and may occur spontaneously during the clonic phase. During head-only stunning broilers may sometimes display intensive wing flapping during and after stunning, which is caused by the grand mal insult (Lambooij et al., 2014).

A human being is unconscious during the three phases of a general epileptiform insult (Lopes da Silva, 1983). By analogy, a vertebrate is also considered to be unconscious and insensible during such an insult. The analogy postulated rests on

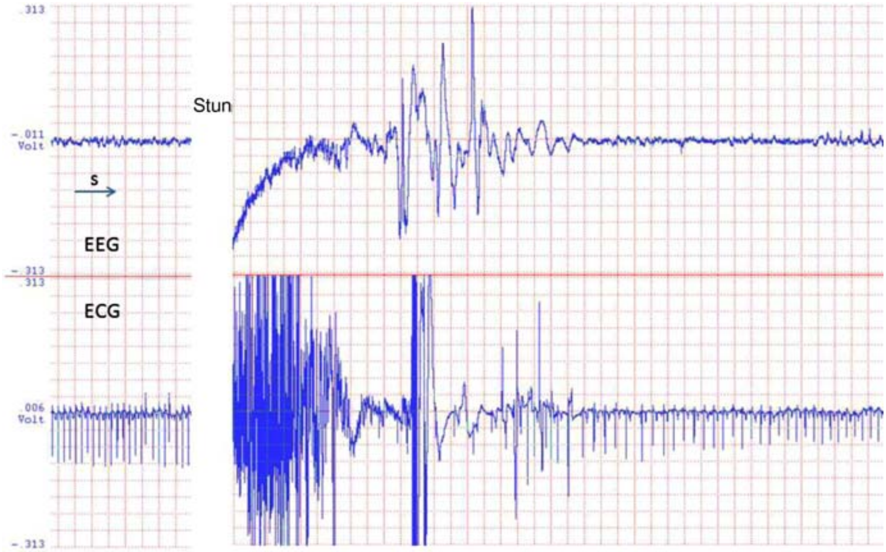

Figure 4.3 Electroencephalogram (EEG; upper trace) and electrocardiogram (ECG; lower trace) before and after head-only stunning (average 264 mA; ~130 V; 50 Hz; AC). Prior to stunning a normal EEG and ECG can be observed. After stunning a tonic phase for 4 seconds is followed by a clonic phase of 4 seconds and minimal brain activity onward. On the ECG, heart fibrillation for 9 seconds is followed by malfunction. The bird recovered from this stun.

the homology of brain structures and similarities in behavioral patterns between humans and vertebrates in situations in which humans experience and report positive or negative feelings. Moreover, the brain is in a stimulated condition and unable to respond to additional stimuli. An additional aspect is that the brain releases several neurotransmitters during such an insult. Several studies, in which neurotransmitters have been measured, coupled with pharmacological experiments, suggest that the general epileptiform insult induced by an electrical stun is dependent on the release of vasopressin, oxytocin, glutamate, aspartate, and GABA (Cook et al., 1996).

Brain tissue impedance has been used as a measure of changes in the extracellular volume and has been found to be a valid indicator of insensibility in ischemia-induced brain damage experiments in broiler chickens. Animals that were bled showed a decrease in base extracellular volume after 4 minutes postmortem, while electrical head-body stunning, inducing cardiac fibrillation, caused an immediate and gradual increase in brain impedance. This suggests that the latter method provides an immediate effect on the brain. Head-only stunning with exsanguination caused a dual response pattern. Some broilers showed a response similar to broilers that were bled only, and some were similar to those experiencing head-body stunning. Various physiological processes may contribute to this effect. It cannot be stated conclusively from this experiment that head-only electrical stunning provides an adequate stun (Savenije et al., 2000).

It is generally accepted that for poultry unconsciousness should occur immediately (within 1 second) after an electrical stun and that the animal should remain in a state of unconsciousness for the duration, from the end of the stun until death. A minimum of 40 or 52 seconds, depending on the combination of stun duration and current levels, has been considered a sufficient period of unconsciousness for poultry to meet that criterion (Gregory and Wotton, 1990; Raj, 2006).

4.3.2 Stunning and exsanguination

Stress before slaughter increases some neurotransmitters, which may affect poststun reflexes and unconsciousness. Combining head-only stunning with exsanguination has a synergistic effect on the release of glutamate and aspartate, which increases the duration of unconsciousness and insensibility. Sticking (also referred to as slaughter, exsanguination, or bleeding) following a stun should be carried out as promptly as possible when using head-only stunning because it takes longer, depending on the species, before brain responsiveness is lost following sticking. It is recognized that inducing a cardiac arrest at stunning has distinct welfare advantages: (1) it results in a rapid loss of brain function; (2) it ensures that the animal will not regain consciousness; and (3) it does not depend on the slaughterman performing an accurate stick (Lambooij et al., 2014). Sticking should involve severance of blood vessels supplying oxygenated blood to the brain. For example, sticking involves severance of the brachiocephalic trunk at the thoracic inlet in cattle and pigs, while in sheep, goats, and poultry it involves severance of both the carotid arteries in the upper neck.

4.3.3 Waveform and frequency

For stunning, the minimum current necessary to induce unconsciousness and insensibility depends upon the waveform and frequency of current used. Electricity can be supplied at frequencies up to 1800 Hz and the waveform can take on various shapes, i.e., square or rectangular or combinations thereof. The most commonly used electrical stunning method for poultry uses a frequency of 50 Hz alternating current (AC) with a sinusoidal waveform. High-frequency electrical stunning can induce epileptiform activity in the brain; however, relatively higher currents are necessary to induce epileptiform activity (Hindle et al., 2009; see also Table 4.2).

Table 4.2 Minimal required current (mA per bird) when using a water bath stunner (European Council Directive 1099 (2009))

Stunner frequency	50 Hz	Up to 200 Hz	200–400 Hz	400–1500 Hz
Poultry type	Minimum current			
Broilers	100	100	150	200
Spent hens	100	100	150	200
Turkeys	150	250	400	400
Ducks, Geese	130			

A sufficiently prolonged period of unconsciousness and insensibility (e.g., 40 seconds) is required to facilitate exsanguination and onset of death. In this regard, a bipolar sine or a square wave has been found to be more effective than a monopolar pulsed direct current (Hindle et al., 2009). During "head to body" stunning where a 50-Hz sine wave (AC) passes simultaneously through the brain and heart, the animal may die due to heart failure. The heart failure leads to a loss in blood pressure and a reduction in oxygen supply to the brain and results in the characteristics of a general epileptiform insult.

At present a variety of waveforms and frequencies of currents can be used for stunning. Alternatives for the sinusoidal AC current include pulsed direct and pulsed AC. It is suggested that the depth and duration of unconsciousness induced by electrical stunning is determined by the duration for which the current maintains a minimum application level within each cycle (RMS-current, duty cycle, AC/DC) (Hindle et al., 2009) (Fig. 4.4).

A combination of frequency in relation to waveform and current supply can induce a variety of conditions including immobilization, sleep, anesthesia, stunning, and convulsions. A direct constant current has been introduced to immobilize animals prior to handling (Hindle et al., 2009). A low current (50 Hz) can be used to immobilize broilers to allow automation of the neck cutting procedure for bleeding out. Stimulation of the cortex and brain stem using 50−300 pulses per second (300 Hz) may introduce desynchronized sleep. Anesthesia can be induced by

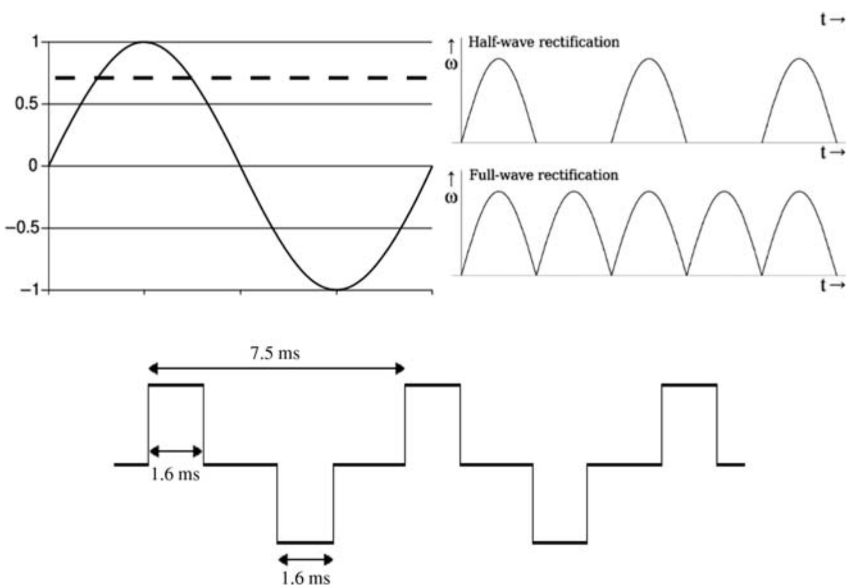

Figure 4.4 Sinusoidal, pulsed, and pulsed square waves are used to stun poultry. The amplitude, width, and frequency can be changed and affect induction of unconsciousness.

stimulation with 100−100,000 Hz for 3 milliseconds delivered at 18 mA. Spasms, irregular breathing, and cardiac arrhythmia have been induced by allowing a longer duration or applying a higher current. Irregular rectangular pulse currents are assumed to decrease the muscular spasm(s).

Alternative waveforms may be effective in inducing a general epileptiform insult (unconsciousness). However, due to the high currents required, hemorrhaging is unavoidable. Therefore alternative waveforms should be introduced with caution as they do not appear to help alleviate the problem of blood splashing after stunning (Hindle et al., 2009).

4.4 Stunning methods

4.4.1 Water bath stunning

Water bath electrical stunning is commonly used under commercial conditions where large throughput rates are required. A large proportion of the stunning, killing, and slaughter process is automated. However, as discussed earlier transfer of the broilers from the transport crates to the shackles remains a manual task. In this system, the birds are passed through the electrified water bath such that the current flows through the whole body (head to foot) toward the shackle, which serves as the earth. The water bath is electrically live so that each bird is stunned from the moment it makes contact with water (Bilgili, 1999; Fernandez, 2004).

A minimum current of 120 mA (50 Hz) per bird in the water bath is recommended in the EU to apply sufficient power to force the current through the body and induce unconsciousness and a cardiac arrest (Gregory and Wotton, 1990). In the heart, as in the brain, the neuronal interactions are integrated and orderly. Disorder is initiated by direct stimulation with the electrical current causing the heart to fibrillate or stop. However, this EU recommended minimum current for broilers increases the risk of quality defects (hemorrhages, broken bones) in the carcass and meat (Gregory and Wilkins, 1989; Veerkamp and De Vreis, 1983). Therefore it is apparent that there is a conflict between concerns for bird welfare and those for product quality when using the electrical water bath stunning and killing procedure.

Effective electrical stunning using a water bath requires that

- water baths for poultry are adequate in size and depth to accommodate variable types of bird;
- the height of the bath is adjustable to allow for the head of each bird to be immersed;
- the electrode immersed in the bath extends the full length of the bath;
- birds are immersed in the bath up to the point where the wings join the shoulder;
- the control box/panel incorporates an ammeter which displays the total current administered to the birds;
- the voltage is adjustable to ensure application of the total current required for each type of bird as shown in Table 4.2, and each bird receives the appropriate current for at least 4 seconds.

It is recommended to ensure that the shackle-to-leg contact is wet, preferably before the birds are placed in the shackles. Additional salt, in solution, can be added to the water bath to maintain appropriate constant concentrations. Every effort must be made to ensure that no conscious or live birds enter the scalding tank. A manual back-up system should be in place to ensure that any birds that avoid the water bath stunner and/or the automatic neck-cutter are immediately stunned.

The presence of several birds at the same time in the water bath creates a parallel pathway of resistance. It has been claimed that under slaughterhouse conditions only about one-third of birds are effectively stunned, while one-third are inadequately stunned and the remaining third undergo cardiac arrest (Woolley et al., 1986a,b). The shackles and framework, together with the bird itself, form a conductive resistance to the current and are therefore potential sources of loss of electrical capacity. These sources of resistance are variable according to bird resistivity (skull bone structure and thickness; Woolley et al., 1986a,b) and shackle condition (degree of fouling, contact area with bird). These variations in resistance can influence the quality of the stun so that some birds receive too much while others receive insufficient current. Ultimately, this can lead to problems with either bird welfare (failure to lose consciousness or rapid recovery) or product quality (hemorrhaging, bone fractures).

For many years the practical solution to quality defects such as hemorrhaging and broken bones has been to increase the frequency of the power supply and/or to change the waveforms. However, research has shown that by increasing the frequency the effectiveness of electrical stunning will decrease (Hindle et al., 2009). Based on these findings, recently revised European Council Directive 1099 (2009) demand application of higher currents for stunning poultry at higher frequencies (Table 4.2). This indicates that, for electrical water bath stunning, broilers stunned at <200 Hz should receive a current of 100 mA. At frequencies between 200 and 400 Hz a current of 150 mA is required and for 400–1500 Hz a current of 200 mA. From an animal welfare perspective the higher currents at higher frequencies, although on the one hand providing an assurance of inducing unconsciousness and insensibility, will on the other hand, be detrimental to product quality by increasing incidences of muscle hemorrhaging and skeletal damage.

The most effective current has been identified as one which is supplied at frequencies between 50 and 200 Hz. This indicates that it becomes difficult to induce an adequate seizure when using frequencies lower than 25 Hz. At higher frequencies, between 200 and 1600 Hz, a higher current is required to induce the seizure. However, the duration of the insult is shorter.

Recovery (percentage of birds) after water bath stunning varies:

- 100 mA, 50 Hz → 10%–20%
- 150 mA, 400 Hz → 50%
- 200 mA, 1000 Hz → 70%

Present water bath stunning equipment in slaughterhouses does not allow accurate and rapid measurement and control of individual current supply and bird impedance. The actual current that a bird receives during electrical water bath stunning will vary according to the number of birds in the water bath at any one time. As previously discussed, individual variability in impedance dictates whether or not some birds are effectively stunned (Hindle et al., 2010). Eventually, any modified and/or alternative electrical stunning methods under development will have to be assessed under abattoir conditions (EFSA, 2012).

4.4.2 Head-only stunning

Alternative methods to whole-body electrical stunning include variations such as head-only (Hillebrand et al., 1996; Lambooij et al., 2010; Lines et al., 2011a,b) and head-cloaca techniques (Lambooij et al., 2012). However, restraining the bird, and particularly fixating the head, remains a challenge to success of performance. At present, several pilot designs for an automated head-only model are currently being tested under commercial conditions. As yet, none of these potential options have resolved the need to handle and invert the birds. Hillebrand et al. (1996) showed that placing broilers in a cone during stunning and exsanguination limited convulsions making this, in their view, more esthetically acceptable (Fig. 4.5). However, this design still requires inversion of the birds and the authors did not comment further on the welfare aspects of this restraining method, other than to speculate that the reduction in hemorrhaging seen is probably related to the reduction in convulsions.

It was demonstrated that broilers can be made insensible and unconscious after head-only electrical stunning in a cone-shaped restrainer with pin-electrodes using a current of 190 ± 30 mA for 0.5 seconds (Lambooij et al., 2010). For practical implementation, a fixed current set at 250 mA was recommended to overcome

Figure 4.5 Head-only electrical stunning. The broiler is restrained in a cone with open electrode plates just before stunning.

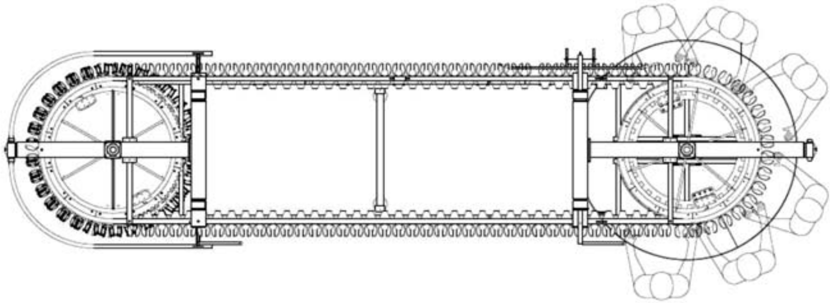

Figure 4.6 Design of prototype head-only stunning model using a cone-shaped restrainer. The operators place the broilers in the cone on the right and the chickens are transported clockwise to the stunner on the left side of the figure. Thereafter, the broilers are shackled automatically and a neck cut is performed (manually).

differences in resistance between individual birds. In order to avoid the risk to animal welfare by recovery of consciousness the stun should be followed by an immediate neck cut (Lambooij et al., 2014).

A prototype head-only stunner using cones to restrain the birds was placed in a commercial slaughterhouse. After a brief introduction and testing period, slaughterhouse personnel were capable of correctly positioning broilers in the cones (Fig. 4.6). Six operators could place the broilers correctly in the cones at a line speed of 7000 birds per hour. They reported that this required less effort than hanging the birds in conventional shackles at a similar speed. The procedure of positioning the birds correctly in the cone-shaped restrainer, however, requires a different handling method and specific motivation to perform this correctly. Broilers were restrained in the cone with their heads positioned to facilitate a correct stun, followed by a neck cut by hand. After stunning, each broiler displayed a tonic phase, followed by minimal brain activity during bleeding. No responses to pain stimuli were detected on the EEG, although one bird did show a behavioral response. Heart rate was on average 258 ± 51 beats/min prior to stunning. Based on EEG recordings, the broilers appeared to be insensible and unconscious after head-only electrical stunning in this system. Within a confidence limit of 95%, taking into account the number of animals with a reliable EEG ($n = 27$), the chance of an effective stun of all broilers lies between 0.90 and 1.00 with an application current of 264 ± 29 mA (~ 130 V) (sinusoidal AC). Neck cutting occurred within an average of 14 ± 2 seconds after stunning, and the heart was observed to malfunction after neck cutting.

4.4.3 Head-cloaca stunning

Certain aspects are essential to the success of electrical stunning of poultry, including adequate contact between the bird and the electrodes, level of current administered, duration of the stun, and reduction in impedance. It was hypothesized that the placement of electrodes in order to bypass the feet and legs would result in efficiency gains by utilizing lower currents (Lambooij et al., 2012). Use of alternative waveforms to the standard sinus waveform could also improve efficient use of electricity. Tests have been performed where individual birds were hung by the feet from the shackles and stunning was performed as the bird's head was immersed into a bath. The electrical current ran from the head to the rear of the bird. At the rear a double or a single bar was lowered into position on to or in close proximity to the cloaca. These stainless steel bars formed the second electrode through which the electrical current passed from the bird. Broilers were effectively stunned with an average current of 111 mA (50 V; 640 Hz; sinusoidal AC) for 0.5 seconds. Additional tests have been performed applying a pulsed square wave with an AC with a 32% or 43% duty cycle. However, the voltage and amperage required to induce unconsciousness could not be reduced. This method showed encouraging results under laboratory conditions, but has not been investigated further due to practical problems in commercialization.

4.4.4 Transcranial Magnetic Stimulation

Complete alternatives (starting from scratch) are rare. Use of Transcranial Magnetic Stimulation (TMS) has been suggested as a possible alternative capable of providing a pain-free stun. Magnetic seizure therapy was originally introduced for the therapeutic electric shock treatment of psychiatric and neurology patients during the 1980s (Barker, 2002). TMS involves the creation of an electromagnetic field that induces an electrical current within the brain. For stunning animals, the head of the animal is placed between or in close proximity to copper coils which can be built into a cap or pair of tongs. The brain acts as a conductor through which the current circulates and initiates a grand mal seizure. In practice, a large current is forced through the coil creating an electrical field which in turn generates a magnetic field that penetrates the surface of the brain lobe that is in close proximity to the coiled copper probe (George, 2003). Research with rabbits has shown that it is possible to render them unconscious using magnetic stimulation in this manner (Anil et al., 2000).

A TMS device, patented and manufactured in England (Magstim rapid, Spring Gardens, Withland, Carmarthenshire, Univ., Bristol, GB) was used during a pilot study on broilers (Lambooij et al., 2011). This pilot study demonstrated that TMS induced a reduced state of consciousness for between 10 and 20 seconds irrespective of the design of copper coil used. A reduction in the amount of power generated by the stimulator from 80% to 51% resulted in a reduction in duration of unconsciousness (10–15 seconds); thereafter all animals became drowsy and gradually regained consciousness. This test indicates that in principle TMS can be used to stun poultry. Further development of this technique requires essential investment into the development of equipment. Further improvements can only be established through laboratory animal trials, and trials will also have to be performed under (semi-)commercial conditions to establish the commercial potential and prospects for this technique.

4.5 Meat quality

Hemorrhaging is the most common meat quality problem with electrical stunning. In this section the problem will be discussed with comparisons made to other kinds of stunning that could be used in commercial plants, including gas and mechanical stunning.

4.5.1 Hemorrhaging

Hemorrhaging results in a decrease in quantity (trimming) and quality of poultry products, and hence causes economic loss to the poultry industry. In particular, hemorrhaging of the valuable breast meat is a major concern for maintaining quality standards. Hemorrhages can be induced by stunning, however, the underlying mechanism is considered to be multifactorial (Kranen et al., 2000a).

The morphology of hemorrhages investigated was dependent on the tissue in which they occurred (Kranen et al., 2000b). In the pectoral muscles, extravasate blood was found to flow in the direction of the muscle fibers. In fat tissue, the majority of the hemorrhages had a petechial appearance. More diffuse hemorrhages were found in loose connective tissue. Histological examination of hemorrhages in different types of muscles showed that the morphological appearance of the blood extravasation is determined by the structure of the tissue together with the amount of blood leaving the circulation. Some hemorrhages were associated with hypercontracted and disrupted muscle fibers, indicating that they were caused by severe muscular strain. Many hemorrhages were found near venules or veins packed with erythrocytes and surrounded by intact adipocyte and connective tissue. Rupture was observed only in venous structures, such as postcapillary venules and small veins, but not in arterial vessels. These observations provide a strong indication that a local rise in venous blood pressure can cause rupture of venules and small veins.

4.5.2 Muscles

Various stunning methods and electrical parameters have been reported to display different effects on postmortem rigor development and subsequent meat quality in poultry. High-current electrical whole-body stunning at 100 mA and above resulted in higher initial muscle pH than stunning using methods other than electrical or electrical stunning at 50 mA or lower (Papinaho and Fletcher, 1995). Lower, or similar, breast muscle shear values were observed in birds whole-body stunned with currents lower than 100 mA in comparison to those stunned with currents above 100 mA (Papinaho and Fletcher, 1996).

4.5.3 Electrical versus mechanical stunning

In comparison to electrical whole-body stunning, stunning using air pressure (2 atmospheres) with an injection time of 0.5 seconds resulted in less blood loss without adversely affecting muscle hemorrhaging. The incidence of hemorrhaging and pectoral bone fractures was reduced after air pressure stunning. Restraining the bird in a cone-shaped restrainer, frequently used for air pressure stunning, reduces thigh muscle hemorrhaging as compared to shackling. Muscle glycolysis was accelerated after air pressure stunning and the meat was therefore tenderer than that produced after electrical whole-body stunning. Although air pressure stunning compared to conventional electrical whole-body stunning improves meat quality, more research is required into the development of a suitable stunning and restraining device for commercial use (Lambooij et al., 1999).

4.5.4 Electrical versus gaseous stunning

Gas stunning methods are increasingly being used in slaughter plants for meat birds. A variety of different gases have been investigated for use, including carbon dioxide (CO_2) and argon (Ar). A higher incidence of wing damage occurs during gas stunning compared to electrical stunning (Raj et al., 1992). This increase in wing damage was found to be a consequence of severe convulsions during gaseous stunning. However, gas killing of broilers has also been considered to substantially reduce the incidence of broken bones and hemorrhaging in breast muscles (Raj, 1997; Uijttenboogaart, 1997). Differences in the rate of postmortem glycolysis, induced by other stunning procedures, such as gaseous stunning, have been reported to result in differences in meat quality traits such as color and texture (Raj, 1994). When compared with high-frequency electrical stunning, killing of broilers using Ar gas resulted in lower bleed-out levels, which may be responsible for the increased incidence of carcass downgrading observed.

Different gas mixtures have different effects on meat quality as compared to electrical stunning (Uijttenboogaart, 1997). Blood clotting was less evident after CO_2 gas stunning compared to electrical stunning. The liver from gas stunned birds was darker, with more red and less yellowing, compared to electrically stunned birds. Breast meat of CO_2 stunned birds is lighter than that from electrically and Ar stunned birds. Heme content in liver and breast meat is also affected by stunning technique. Breast meat from gas stunned birds has significantly higher levels of heme compared to that from electrically stunned birds. Furthermore, heme levels in the liver tend to be higher in gas stunned birds. In practice, when using gas stunning systems attention has to be paid to the duration and intensity of the plucking operation, because more feathers remain on the carcass than after electrical stunning. Argon stunning resulted in a sharp decrease in pH in comparison to the other two stunning systems (electrical and CO_2). It is considered that probably due to the convulsions that occur during the stun/kill operation in Ar, the meat pH is already lower than when using the other stunning techniques, during which no or fewer convulsions occur. After 24 hours of chilling no differences were observed in meat quality between the stunning methods used. A very significant effect of ageing/boning was found for shear, water binding, and sensory parameters.

4.5.5 Head-only versus water bath stunning

Studies of water bath stunning have shown that more than 67% of the broiler carcasses stunned at 50 Hz displayed blood spots, 85% of which were from broilers that died during the stunning procedure. Stunning at 400 Hz produced 35% of carcasses with blood spots of which 81% were from broilers that died during the stunning procedure (Hindle et al., 2010). Stunning at 1000 Hz resulted in 18% of carcasses with blood spots of which 88% were from broilers that died during the stunning procedure. Although there appears to be a tendency toward fewer incidences of blood splashing as frequency increases, the EU stun to kill policy does not appear to improve the situation (Hindle et al., 2010).

During head-only stunning (Lambooij et al., 2012) broilers sometimes display intensive wing flapping. Wing flapping may cause broken wings and induce hemorrhaging. This is a disadvantage of head-only stunning in comparison to the water bath method. However, as suggested previously, the introduction of a cone-shaped restrainer may prevent excessive wing flapping. Considerable differences in fillet quality have been observed in broilers stunned head-only. Approximately 80% of these fillets showed no blood splashes and the remaining 20% did not display any severe blood splashes. This was an improvement on the level of blood splashing observed in the control birds stunned in a conventional water bath. Meat pH after chilling was 0.5 units lower ($P < .05$) in the head-only stunned group than in the group stunned in a conventional water bath. After head-only stunning 60% of breast fillets showed no blood splashes and 3% showed severe blood splashes compared to 20% and 27% after conventional water bath stunning. No differences in temperature and color were observed between the two groups.

4.6 Ethics

Important information from neurophysiological studies has provided valuable insight and support to improve knowledge and understanding of the stunning process. The inclusion of additional assessment parameters other than those observed during the general epileptiform insult and analgesia may help to improve the humaneness of the stunning and killing system. EEG and neurotransmitter release measurements have been used to assess the effect of electrical head-only stun duration on welfare. An understanding of the physiological mechanisms that are responsible for the visible reactions to electrical stunning may help us to understand the effect of several conditions on the effectiveness of stunning and killing. Stress before killing increases certain neurotransmitters, which may affect poststun reflexes and unconsciousness. Combining head-only stunning with exsanguination has a synergistic effect on the release of glutamate and aspartate, which increases the duration of unconsciousness. Sticking following a head-only stun should be performed immediately. A major issue of concern is whether or not stunning actually renders the animal unconscious and insensible.

4.7 Advantages and disadvantages

Advantages of electrical systems include the following:

- Birds can potentially recover after head-only stunning, which may make the method acceptable for Halal slaughtering
- No chemical contamination of tissue and organs
- Low running costs

Disadvantages of electrical systems include the following:

- Risk to operators
- Difficult to perform successfully with restless animals
- Some people find it esthetically repulsive
- Smaller birds may lift their heads and avoid stunning
- Hemorrhaging
- Handling, inversion, and shackling of live animals
- Birds recover after head-only stunning, which is a potential risk to bird welfare

4.8 Conclusions and implications

Given some of the disadvantages of shackling and water bath electrical stunning, future developments should be aimed at improving animal welfare during restraint and handling while developing more efficient stunning methods to meet increasing throughput demands. The search for alternative stunning/killing methods has to be continued.

One specially designed alternative, with a conveyor belt under the shackle line devised as horizontal breast support for the inverted birds with their legs extended behind them in shackles, was shown to effectively reduce incidences of struggling birds and improve water bath entry. This indicates the potential of this design to reduce animal welfare risks such as prestun shocks, wing flapping, and convulsions. Further investigation and development would seem a logical course to follow, however, until now this has not been the case. A fully automated version of this conveyor system has been technically accomplished yet it remains unclear whether it has been or will be developed further.

It is hypothesized that the improvement of stunning efficacy together with a reduction in the number of quality defects can be achieved by placement of electrodes so as to bypass the feet and legs while utilizing lower currents. In addition, as technical developments progress it should become possible to stun broilers individually instead of in a multi-bird water bath. Recent research indicated that broilers are effectively stunned with a controlled current using a water bath where the head of individual broilers is immersed in the water and a steel electrode is placed at or around the cloaca as the opposite electrode. The evidence that there are fewer blood splashes in both the breast fillets and legs of carcasses using head-cloaca stunning techniques compared to those stunned in a conventional water bath indicates that there should be further examination of the possibilities for commercialization of this technique.

An alternative approach under development for commercial use is head-only single-bird electrical stunning. Head-only stunning uses a cone-shaped restraining device in which the broilers are suspended by their feet. A set current of 250 mA for at least 3 seconds is recommended to overcome individual differences in resistance. To prevent recovery the stun should be followed by an immediate neck cut. Since carcass quality is only slightly compromised such equipment is now being developed for commercial use. However, the problem of having to invert the birds has not yet been resolved.

A complete alternative to conventional methods of electrical stunning is the use of TMS of the brain. Further development of this technique requires essential investment into the development of equipment. TMS has potential for application as a non-invasive stunning method for broilers and could provide an acceptable alternative to conventional methods for some religious groups.

Finally, it is probably still the case that the greatest challenges remain in terms of safeguarding animal welfare and improving production levels while at the same time attempting to secure product quality at an acceptable price level for the consumer.

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Gas and low atmospheric pressure stunning

5

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5.1 Introduction

Today, stunning is recognized as a critical step in the humane slaughter of animals for food, since it renders birds unconscious or insensible. It is also critical to present the bird in the correct posture for automated killing machines (Fletcher, 1999). Properly done, stunning minimizes pain and suffering until the bird is dead from either the stun itself or from exsanguination.

The first stunning systems used electricity and this continues to be the most common method around the world (Berg and Raj, 2015). Bird size, line speed, bird activity, and other factors present some serious issues with this method, as it is possible for birds to miss the stunner entirely or for birds to be understunned and thus not insensible at the time of the throat cut (Boyd, 1994; Zivotofsky and Strous, 2012). In the worst of circumstances this would lead to live birds entering the scalding tank, which is absolutely unacceptable.

During the 1980s, the increased awareness of animal welfare and the accumulation of scientific data indicating that there are several potential issues with electrical stunning led to the search for improved or alternative methods. As early as 1957, Kotula and associates investigated the effect of carbon dioxide gas (CO_2) immobilization on the bleeding of chickens. At the time, stunning prior to exsanguination was not commonly practiced in the industry.

5.2 General concepts

When considering the welfare of poultry during slaughter, two of the five freedoms (Farm Animal Welfare Council, 2009) are directly applicable. The two are freedom from pain, injury, or disease and from fear and distress. The first area of concern related to stunning is the method of delivering the birds to the system. That is, are the birds removed from the transport container and if so, by what means?

With electrical systems, removal either by hand or unloading using a dumping or slide-type system has the potential for causing pain, injury, and fear (Duncan, 1989; Jones et al., 1998). Issues with slide-type unloading systems include fear from the action of the system and potential for a bird to be pinched by being trapped between the slide and the belt or landing on another bird. In addition, chickens can become

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trapped by having a foot or a wing caught in the container vent holes. With hand removal from a transport container the birds are handled by humans, which presents the potential for both fear and pain from the action of lifting the birds by their feet through a door in the container or from a drawer where they might be damaged by contact with the container walls (Duncan, 1989).

The next area of concern is whether or not the birds are shackled while sensible, again with potential for both pain and fear. For shackling the birds must be handled by humans and that action has been shown to cause stress in the birds (Duncan, 1989; Jones et al., 1998). In addition, pain sensors in the feet and shanks make the placement in the shackles painful as well as stressful (Gentle and Tilston, 2000; Sparrey and Kettlewell, 1994). Most commercial controlled atmosphere stunning (CAS) systems remove these issues by stunning the birds in their transport containers. While the methods for controlling the atmosphere differ, both low atmospheric pressure stunning (LAPS) and gas stun systems can be classified as controlled atmospheric stunning. The differences are in the basic operating systems.

In the case of gas systems there is another variable, which is whether or not the birds are simply stunned and could fully recover (i.e., reversibly stunned, commonly known as CAS) or irreversibly stunned (i.e., controlled atmosphere killing [CAK]), so recovery is impossible. Electrical stunning is instantaneous while all CAS and CAK systems include a delayed onset of insensibility.

During the onset phase of stunning with CAS and CAK systems there are concerns about the experience of the birds during this process. The length of time of exposure to noxious gas or other changes that might cause distress, pain, or fear must be considered. Widely accepted measures of this are observation of behavior and use of electrical encephalography (EEG) and electrocardiogram analysis (ECG).

Behavior indicative of distress includes escape attempts indicating fear, headshaking which indicates arousal or awareness, ataxia or loss of posture and convulsions observed as wing flapping (McKeegan et al., 2013). Physiological indicators of distress can be measured using EEG and ECG. The EEG data can pinpoint changes in brain activity that indicate arousal as well as onset of insensibility. The ECG measurements of heart rate can indicate a fear response through an increase in heart rate (Coenen et al., 2009) Respiration can also be observed and evaluated to indicate distress. For example, deep breathing or gasping is indicative of oxygen deprivation or respiratory distress (Raj, 2006).

Regardless of the method used the stun cycle must be evaluated for adequacy. In the case of a reversible stun, birds should be able to recover at 120 seconds. A typical bleed time is 120 seconds, so recovery before that time would be a welfare problem. With irreversible stuns there should be no recovery and this can be evaluated using standard techniques. These techniques include the absence of reflexes such as from comb pinch or corneal touch, cessation of breathing, and the absence of heart beat (Erasmus et al., 2010). If a stun is found to be inadequate, immediate corrective action must be taken.

While not required, a back-up system or plan should be in place. In the case of a few or single birds, the person backing up the automatic knife can take care of the birds with a quick cut. While this is not a desirable method, it is quicker than removing the birds from the shackle and placing them back on the line. In some cases, manual euthanasia using an approved method such as cervical dislocation can be used. However, if the stunning system is not working properly neither of these methods is acceptable for either the welfare of the birds or production. In these cases, other back-up systems must be in place. The most common back-up method is an electrical water bath stunner, as it can be shut off during normal operation and put back into operation when needed with minimal delay.

Slaughter of poultry must include consideration for the quality and safety of the finished product. Blood is an ideal bacterial growth medium and therefore as much as possible it should be removed from a carcass during slaughter (FAO, 1991). Therefore the ability of the bird to bleed is a concern with any new process. Poole and Fletcher (1995) demonstrated that gas stunning systems produced an adequate blood loss for processing and Vizzier-Thaxton et al. (2010) found that LAPS also produced adequate blood loss.

United States Department of Agriculture, Food Safety and Inspection Service regulations prohibit the sale of animals that died from causes other than slaughter. These animals are commonly known as “cadavers” and often are dead on arrival at the processing facility. Others are the result of failure of exsanguination so that the presence of blood gives them a cherry red appearance. Since for food safety reasons they cannot be processed, they must be separated from the slaughtered birds (USDA, 2014). With birds stunned using CAS this process is more difficult than it is when birds are shackled before stunning. However, a combination of carcass temperature and color along with the presence of rigor is commonly used to determine the status of these carcasses (Duncan, 1997; USDA, 2014).

5.3 Gas stunning

Stunning chickens using carbon dioxide (CO_2) was first investigated in the 1950s as a means of obtaining a better bleed and later to improve the killing cut by immobilizing chickens in the shackles (Kotula et al., 1957). Until the 1980s there was little interest in the use of gas stunning for poultry. However, welfare concerns with electrical stunning led the Farm Animal Welfare Council (1982) in the United Kingdom to request research into alternative methods of stunning to reduce the number of birds inhumanely slaughtered. Based on the use of CO_2 for stunning pigs, the feasibility of its use for stunning poultry while in the transport container was the suggested method.

Since the early studies with CO_2, both mixtures of gases and single anoxic gases have also been studied for their effects on the welfare of the birds in addition to CO_2. The presence of chemoreceptors sensitive to CO_2 produces an aversive reaction to relatively low concentrations of the gas, which raised welfare concerns. The absence of chemoreceptors for inert gases, nitrogen and argon, and their anesthetic properties in the presence of oxygen led to investigations of them for their potential use in stunning poultry. There is no perfect system, as each has a benefit as well as potentially causing discomfort for the birds (McKeegan et al., 2013). None of the gas systems are instantaneous, and aversive behaviors are the primary concern with each Kotula et al., 1957; Kotula et al., 1961).

Argon (Ar), a mixture of 60% Ar, 30% CO_2 in air and 40% CO_2, 30% O_2 and 30% nitrogen (N_2) were investigated by Raj (1998). Other gas mixtures studied include nitrogen with less than 2% residual oxygen (O_2), N_2, and 30% CO_2 with less than 2% residual O_2, and a phased induction using a mixture of 40% CO_2, 30% O_2, and 30% N_2 for a prescribed period followed by 80% CO_2 in air. Comparing visual observations with simultaneous EEG recordings, it was determined that the fewest discomfort movements occurred with the phased system (Coenen et al., 2009).

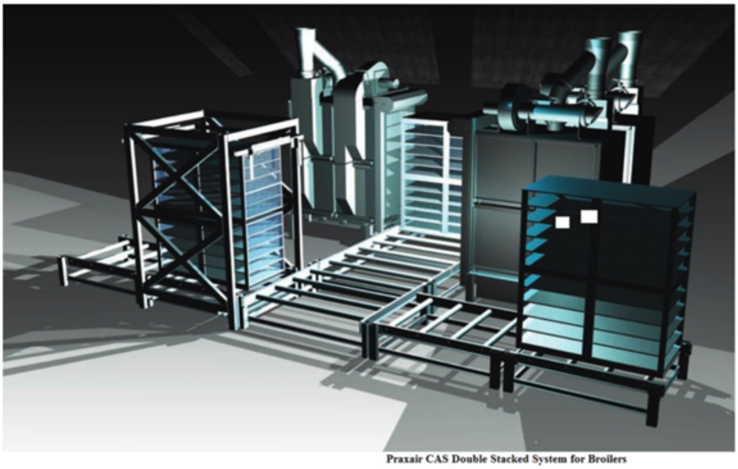
McKeegan et al. (2007) utilized several of the same gas mixtures to evaluate the welfare of the birds during the sentient period. The overall conclusion, based on EEG analysis, was that the activity of anoxic systems resulted in vigorous wing flapping that could potentially be occurring during a period of sensibility. This is a more serious welfare problem than that presented by the respiratory responses with the hypercapic mixtures that included elevated levels of CO_2. Wing flapping in sentient birds is an escape behavior and thus viewed as a sign of discomfort or pain (Sparrey and Kettlewell, 1994).

The most common system in commercial use is a two-stage system. This system uses less than 30% CO_2 during the first phase to take advantage of its anesthetic properties, followed by the second phase which increases the concentration of CO_2 to lethal levels which are above 40% for poultry, ideally to 55% (Raj and Gregory, 1990a,b). This can be accomplished using either linear or vertical equipment (Fig 5.1A and B). The former typically operates with birds placed on a conveyor belt and the latter with birds remaining in the transport containers. In either case the birds move from one concentration of the gas to another via a staged system with increasing levels of $CO_{2.}$

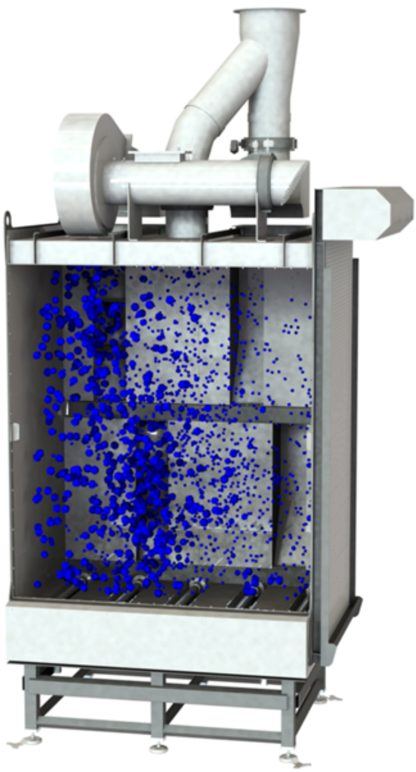
Beyond the selection of gas mixtures there are several variations in the design of gas systems. All of those in current use eliminate the shackling of sentient birds but one system still includes the unloading (dumping/tipping) of these birds. However, Raj and Gregory (1990a,b) noted the potential for air to be trapped in transport containers, thus interfering with the uniform distribution of the stunning gas. So to eliminate that potential issue a system was developed that removes the birds from the transport container to a conveyor belt which moves them through a two-stage tunnel for an irreversible stun. During the first phase of the process birds are anesthetized by exposure to 40% CO_2 and 30% O_2 for approximately 1 minute. From this portion of the tunnel the birds move into 80% CO_2 for the terminal treatment (von Holleben et al., 2012). This second phase lasts about 2 minutes. Upon exiting the tunnel birds are shackled, thus eliminating the pain associated with shackling of sentient birds.

5.3.1 Turkeys

Due to their size, there has been more interest in alternatives to electrical stunning of turkeys than of broilers. A turkey to be sold wholesale in a retail market weighs



(A)



(B)

Figure 5.1 (A) Controlled atmosphere stunning (CAS) system that moves birds in transport container through various levels of gas. The closed cabinet construction allows for the carbon dioxide concentration to be precisely controlled in every stage of the process, ensuring a humane stun and improved product quality. (B) Airflow in vertical multistage CO2 system.

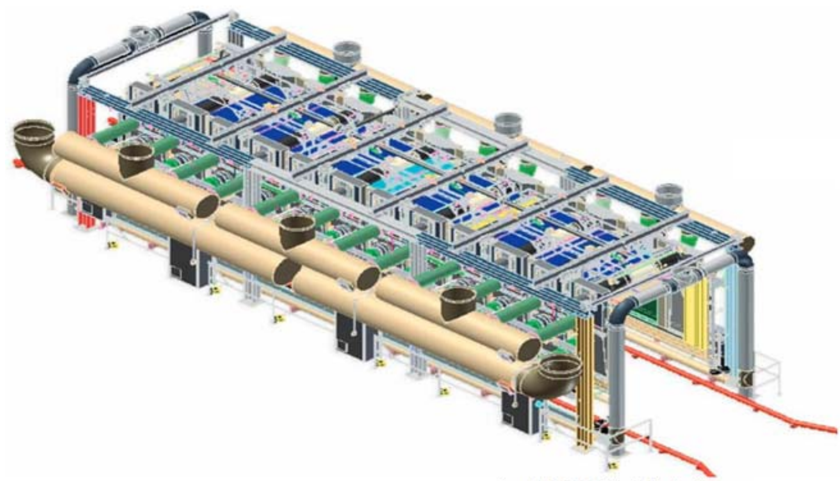


Figure 5.2 Diagram of a Meyn multistage whole truck controlled atmosphere stunning (CAS) turkey stunner using technology developed by Praxair, Inc. It is designed to eliminate the need for live bird handling and has a modular design to accommodate any production volume.
Source: Photo courtesy of Meyn.

between 10 and 20 pounds while turkeys destined for further processing might weigh 40 pounds. Removing a bird of this size from the transport container and shackling it is a very challenging operation and can result in reduced welfare for both the bird and the shackler. Shackling an unconscious or dead bird is significantly easier for the shackler and completely removes the welfare issues for the bird.

Because turkeys can be herded there is no necessity to have mobile transport containers and as a result the containers are permanently attached to the trailer. In order to use a CO_2 system with this configuration, a unit was developed that encloses the entire transport trailer (Fig. 5.2). Once the trailer is placed in the unit the sides of the unit are pneumatically moved to the trailer to seal it so that all turkeys on the trailer are stunned at the same time.

Concern over having the entire trailer simultaneously stunned and the subsequent problems from delays in processing caused the system to be adapted by allowing only sections of the trailer to be stunned. This required shifting the placement of the transport modules on the trailer so that a solid partition could be inserted through them across the trailer (O'Keefe, 2009) (Fig. 5.3). Next the trailers were modified so that each transport module could be removed from the trailer (as is done with broilers) so that the existing CAS systems could be used. One system uses an overhead lift and pulley rather than a forklift to move the modules (Fig. 5.4).

Regardless of the system design, the turkey industry has moved more quickly than the broiler industry in adopting CAS systems as it is a bird welfare improvement and dramatically improves the shackling procedure for the humans assigned to shackle the birds.

Figure 5.3 Single transport unit turkey controlled atmosphere stunning (CAS) unit that allows for both an irreversible and reversible stun of the birds.
Source: Photo courtesy of Humane-Aire.

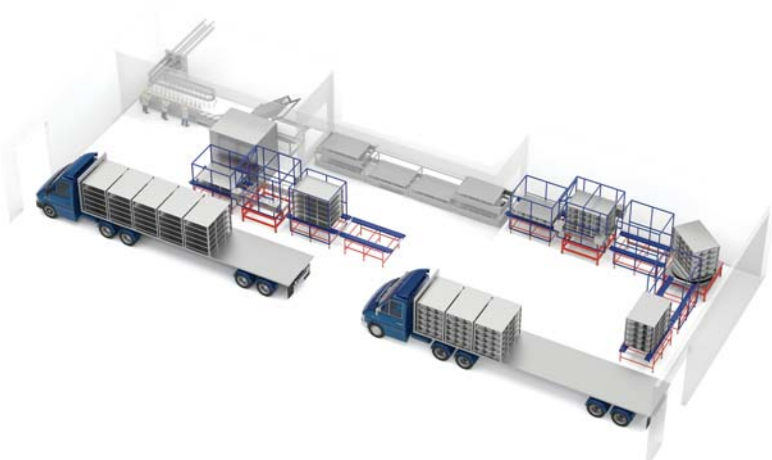


Figure 5.4 Single transport unit turkey controlled atmosphere stunning (CAS) unit.
Source: Photo courtesy of Humane-Aire.

5.4 Low atmospheric pressure stunning (LAPS)

The existence of aversive reactions to various gases and gas mixtures led a group to investigate the use of reduced atmospheric pressure as a means of accomplishing a complete and consistent stun in chickens. Aviation science had demonstrated that this method of obtaining insensibility was not averse in any way to humans, and in fact, produced a euphoric state (Federal Aviation Administration, 2004). The concept was tested in 2005 (Purswell et al., 2007).

After the concept was demonstrated to be feasible, a series of projects were undertaken to move the concept into a commercial reality. The developmental considerations included animal welfare, meat quality, efficiency of operation, operating and capital costs, worker safety, and environmental concerns. Animal welfare criteria were described as 100% effectiveness (i.e., no birds recovered), no damage to the bird's internal organs, and no signs of pain or distress prior to loss of posture. This has to be evaluated by observation of the process and gross necropsy of each bird (Vizzier-Thaxton et al., 2010).

The preliminary study by Purswell and associates (2007) indicated that the speed of pressure reduction was critical and that rapid decompression was completely unacceptable. In this preliminary trial the experimental unit was a cylindrical vessel connected directly to a rotary vane vacuum pump. The unit had a translucent acrylic lid so that observation was possible. The pressure in the chamber was measured with a pressure transducer and the airflow controlled manually. For the tests, the inlet valve was closed to airflow controlled though a second valve. At the conclusion of the test, the chamber was returned to atmospheric pressure through the inlet valve (Purswell et al., 2007). The series of pressure levels tested was selected based on previously published research with hens and humans (Woolley and Gentle, 1988).

Based on the results of this preliminary work, the first studies were performed to determine the rate of atmospheric pressure reduction which prevented the negative signs seen in mammals of varying sizes exposed to rapid decompression, as outlined by AVMA (2007). These signs included pain from expansion of gas trapped in the body, tolerance to hypoxia in immature animals, and accidental recompression. Along with these negative signs those reported for various CAS systems were also evaluated to determine unacceptable processes. These signs included aversion, rapid mandibulation, head shaking, and deep breathing or gasping. Based on earlier research, ataxia or loss of posture was the behavior presumed to indicate loss of consciousness (Raj, 1998; Raj and Gregory, 1990a,b).

Observation of birds in the chamber was determined to be a critical component of the design of each unit so that welfare could be continually monitored. In the first LAPS research units, a viewing window was used. However, the window provided a lens for light to pass into the unit which caused excitement among the affected birds and severely limited the visual field for the viewer. This was replaced with an infrared video camera with a wide angle view so that the birds could be seen in the dark chamber. Maintaining the birds in the dark provides the added benefit of calming the birds. All commercial LAPS chambers are equipped with an infrared video camera equipped with a wide angle lens so that the process can be observed in real time using a LCD computer monitor.

Welfare was evaluated using a series of measures. Initially, these included behavior during the process, damage to the carcasses, corticosterone levels, and blood chemistry. Behavior of the birds during the process was observed. Movements such as head shaking, mandibulation, deep breathing, and wing flapping were selected as the primary observable measurements. In addition to observation, welfare was also accessed using criteria such as damage to the carcass and physiological changes. Damage was evaluated by gross examination of the carcasses for dislocated joints, broken bones, and bruising. Histopathological examination was done on breast muscle (pectoralis major) and the lungs, liver, and intestinal tract. Otoscope and pathology were used to determine that the process did not damage the ear drums (Vizzier-Thaxton et al., 2010).

Next, confirmation of insensibility at loss of posture was validated using EEG and ECG in conjunction with bird behaviors. This study confirmed that loss of posture was a good indicator of insensibility and that the process did not cause any behavioral indicators of aversion (McKeegan et al., 2013). Further studies were conducted to establish the process as humane and similar in response to CAS with inert gases. These studies included behavior, brain and cardiac responses, comparison of behavior during the process with analgesic intervention, and the effect of light on the process (Martin et al., 2016a,b,c).

In addition, since the system was to be used in commercial processing plants, it was critical that the meat produced met the requirements of the plant and its customers, as well as complied with all regulations (Fig. 5.5). Removal of blood after the process was also determined to be adequate for both customer and regulatory requirements (Vizzier-Thaxton et al., 2010). Meat quality was examined along with the effects on deboning time as it might affect aging of breasts before bone removal (Battula et al., 2008; Schilling et al., 2012).

Since the atmosphere is controlled by pressure, there is no impact of animal numbers. Atmospheric pressure is affected by changes in ambient temperature, however. To maintain the ideal rate of reduction and achieve the desired levels thermocouples are therefore used to communicate the ambient temperature to the system controlling the computer, for automatic adjustments. The progression of tests thus resulted in a tightly controlled system that automatically adjusts for temperature and is unaffected by animal mass in the chamber, thus eliminating the welfare concerns associated with those factors.

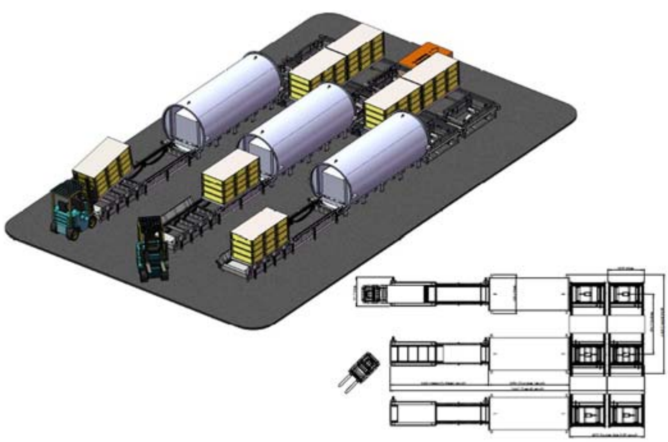


Figure 5.5 A commercial low atmospheric pressure (LAPS) system. The number of chambers and the size of the chambers can be modified for each installation.

5.5 Conclusion

Stunning is a "procedure that induces an unequivocal pathological brain state which is incompatible with the persistence of consciousness and sensibility in order to perform slaughter without causing avoidable fear, anxiety, pain, suffering, and distress." (Raj, 2004). While there are merits to all of the current systems of stunning chickens, there are also shortcomings.

Electrical water bath stunning is still the most common method of stunning poultry. The expense of retrofitting processing facilities to use controlled atmosphere methods has resulted in a reluctance to adopt the newer methods. With gas systems there is also the expense of the gas further affecting acceptance. Meat quality is a factor in accessing the economics of a system. With electrical stunning, overstunning can result in blood spots, bone separation at the joint or breakage, and damage to the liver, all of which cause downgrading or condemnation issues thus lowering the value of the meat. On the other hand removing meat from the bones before the rigor process has completed can result in toughness, which also devalues the meat. To prevent this the front halves of broiler carcasses are often held overnight in coolers before deboning, which is an added expense. Both CAS/CAK and LAPS systems have the effect of minimizing or eliminating this problem, thus increasing their value.

At present these benefits alone have not completely eliminated the extra costs of installing new systems. However, continued pressure from the government, animal welfare groups, and retailers is slowly providing a path for adopting these new methods. The primary goal of these new methods of stunning is the elimination of unloading and shackling of sentient birds. In addition, all forms of controlled atmospheric stunning, i.e., CAS, CAK, and LAPS, can provide improved control and assurance that no conscious bird reaches the knife to provide the best welfare possible with current knowledge.

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Part III

Welfare assessment on the farm

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Welfare assessment of poultry on farm

6

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6.1 Introduction

Poultry are the most common farmed animals on the terrestrial earth. For example, in 2016, around 55 billion chickens were reared for meat (FAO, 2016)—more chickens in 1 year than the estimate for the number of humans who have lived on the planet—ever. The history of chicken intensification has been influenced by three factors—the movement of people from the country to towns and cities, which also moved poultry production from "local" to "centralized": the rise of the use of electricity to ventilate poultry houses, which allowed large farm buildings to house large flocks of poultry, and the use of fossil fuel to enable feed materials to be to be sourced from around the world and poultry meat to be transported great distances. Approximately 75% of poultry meat today comes from birds reared entirely indoors (FAO, 2016), and of the 25% not reared under controlled conditions, the majority are farmed locally, or at subsistence level, although a small percentage of flocks are "returning to the paddock" as people choose to purchase free range or organic poultry.

To help protect poultry welfare (and protect against poultry disease), many countries have laws or industry guidelines directing how poultry should be kept, and often the implementation of these laws (EU, 2007) or guidelines require that inspections take place—either for "enforcement", or for "farm assurance" (Heath et al., 2014; Mench, 2004; Main et al., 2014; Veisssier et al., 2008). During the course of these inspections, it has become apparent that simply "measuring the box," that is establishing that the animals have the required amount of space and access to required resources, provides only the base level of assessment information. Because of this, there has been a general move, fast in some areas and slower in others, to consider and adopt "look at the animal" approaches to assessment in combination with the more established "measure the box" methods. Practically, this move from resource-based measures (RBMs) to outcome-based measures (OBMs) has resulted in the increasing use of "welfare check sheets" to evaluate the welfare aspects of poultry on farm.

In this chapter, I describe some of the OBMs (which are also often referred to as animal-based measures) used to assess the welfare of poultry (not only meat chickens but laying hens and turkeys) on farm, as individuals, and as individuals within groups (see Appleby et al., 2011; Berg et al., 2012; Butterworth et al., 2016; de Jong et al., 2016). Chickens are sentient, capable of feeling pain and avoiding sources of stress, discomfort, and distress when they are given a choice. The farmed

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meat chicken is expected to perform at phenomenal levels—from egg to plate in 32 days—and to not only return something to the farmer in the way of "profit margin" but also to be "readily affordable" for most consumers. What the chicken needs, or could expect to get from this arrangement, is difficult to determine. But it is probably fair to consider that a chicken would seek safety, some "comfort," avoidance as far as is possible of fear, pain, disease, bullying, and mutilation; access to sufficient space to use some of its physiological capabilities—access to food, water, light, air that is not damaging to breathe and a surface to live on that does not cause skin lesions and that enables the performance of some behaviors like dust-bathing, scratching, pecking, and foraging. The questions which are usually addressed about the welfare of farmed animals, and which are used to assess their lives, usually fall into fairly simple categories, as reflected in the Welfare Quality Protocols (2009a,b,c).

1. *Are the animals properly fed and supplied with water?*
2. *Are the animals properly housed?*
3. *Are the animals protected from disease or mutilations, and provided with appropriate veterinary care?*
4. *Are the animals able to express a range of behaviors?*

The surge in interest (and concern) for the sustainability of current agricultural practices has also been a recent driver for interest in the links between production methods, sustainability and animal welfare, and FAWC (2017) summarized some principles with this consideration in mind:

1. *Agriculture cannot be considered sustainable if it is achieved at an unacceptable cost to animal welfare.*
2. *Sustainable agriculture must take account of the fact that farmed animals are sentient individuals.*
3. *Sustainable agriculture must include a duty of care for the physical and mental needs and natures of farmed animals, and must not have a dependency on prolonged or routine use of pharmaceuticals, or on mutilations.*

The "**questions**" above can probably be used to assess the impacts on these "**principles**," and so it seems likely that OBMs will not just be increasingly incorporated into retailer and farm assurance assessments, but also be used as part of assessments (by governments, retailers and "society") of the sustainability of animal production systems.

6.2 Do outcome-based assessments work in the farm setting?

It is possible to assess the resources available to an animal, for example, space, air quality, the nature of the bedding, the number of drinkers and feeders, and these characteristics of the animal's living environment are sometimes described as RBMs. However, there are shortcomings with reliance on RBMs to tell you about animal experience. Welfare is a characteristic of the individual animal and not just of the system in which the animals are farmed, and one animal may appear to do well under a set of RBMs that would cause another animal distress or induce increased levels of disease. Animal welfare scientists have, for some time, proposed that OBMs could provide valid indicators of animal welfare. Practically speaking, for reasons of "utility" and also because there are no (and probably will never be) validated OBMs which can address all aspects of farmed animal experience, it is possible, and common, to combine RBMs and OBMs to give the "widest" assessment of the effects of the farm on the poultry kept there. For example, if animals are lame, or have footpad lesions (assessed using OBMs, lameness scoring, foot pad scores), it may be possible to predict that there will be an effect on lameness and foot pad scores if the litter condition is poor (an RBM), and so by scoring lameness, foot pad score, and litter score, the farmer can see that as he alters (improves) his litter score, the number of animals with foot lesions, and perhaps with lameness, may decrease. After a while, it may be possible to reduce the number of measures —and simply assess the "joint effects of poor litter" by scoring foot pads (scoring for pododermatitis)—but this takes time, as confidence in removing linked measures has to develop.

However, the prevailing view on OBM-based assessment is that, if there is an OBM which can be seen to be practical, valid, repeatable and robust, then this should be used in preference to the use of RBMs alone—because a given litter condition may be good for one animal but poor for another. It is, however, clear that some simple questions, for example, "is the animal thirsty" are not easy to measure and so to answer in a farm situation. There is currently no feasible animal-based measure for dehydration which can be carried out on a poultry farm (although a blood measure could be taken at the slaughterhouse, or it could be theoretically or experimentally "possible" to offer water to animals in a choice test, but this is not so easy to apply in a farm situation).

Animals, including poultry, differ individually in their temperament, their experience, and the way their genetic makeup interacts with their environment. The quality of stockmanship and management practices can also strongly affect the animals' experience of, and response to, a farmed situation. It seems likely that using several measures, where these are available, would provide a more comprehensive view of any particular animal's welfare (Dawkins, 1990; Heath et al., 2014). However, it is also apparent that what is "chosen to be measured" is often an amalgam of: available measures, societally or legislatively required measures (such as stocking density or space allowance), and what the scientific community perceives as credible measures. As an example, it is clear that most breeds of chickens have the anatomical and physiological adaptations required for a life outdoors. They have feathers that can provide waterproofing and thermal protection, they can forage, dust-bathe and nest, and to a degree, clamber up into a tree or roost and fly short distances as protection from predators. Some farmed birds are asked to use all of these physiological adaptations, for example, free range and backyard birds. However, most of the OBMs that are actually available for use in farm assurance do not really ask questions about assessment of the full range of a bird's physiological and anatomical capacities and capabilities. Instead, currently used OBMs applied on farm or at slaughter mainly restrict themselves to the "middle ground" of questions about access to food and water, skin lesions, lameness, response to disease challenges, and effects of litter and ventilation. Hence, OBMs examine what farms provide rather than what chickens could or would do given the opportunity—and so current OBMs used in farm studies tend to confirm, or otherwise, that the farm conditions are "OK"—but do not assess what the chicken would like, or if given a choice, what it would choose. This is perfectly understandable—to focus on outcomes that are visible and/or quantifiable in farmed systems, such as skin lesions, feather condition, mortality, culling, and lameness—these are all credible and "do-able" measures of the welfare of animals on farms as those farms are currently structured and managed, but they do not cover the full range of things which birds can, and do, or could do if they were provided (e.g., access to animals of different ages, or of males in all female flocks, or of the ability to choose material to make a nest) influence the animals' experience of a farmed life.

Some welfare assessment systems do look more "holistically" at a wider range of measures to address aspects of behavioral and human−animal interaction—for example, the Welfare Quality assessment system describes the use of Qualitative Behavioral Assessment, which aims to evaluate the birds' emotional states, and also includes a measure for assessing the birds reaction to close human proximity (Welfare Quality Protocol, 2009c).

To help us understand some of the influences which operate on people who work with and produce chickens, let's look at different viewpoints of some imaginary people who are "users" of poultry to try to "see inside" their perspectives on the welfare of poultry.

A farmer might say, "*we have made the lives of these birds so much easier, they are protected from disease, food is only short distance away, they don't have any risk from birds of prey or foxes. The birds can get on and eat and grow*."

An welfare scientist might say— "*chickens can (and do) dust-bathe, forage, get sore feet and dirty feathers if the conditions in the house are not good, they seek heat if they are cold, they avoid getting wet or dirty if they can etc. I've just been assessing these things in the shed, and some of the things they can do well, and some they can't—so I conclude that their welfare is xxxxxx.*"

Consumers make the decisions which influence what is purchased and what is finally farmed (Kjaernes and Larvik, 2007), and a consumer might say—"*well this growing thing is OK, but what about the life of these birds—if we give them a choice by opening the doors of the house out into paddocks, what do the chickens choose? If we give them access to sunlight versus artificial light, what do they do? If we give them longer lives, can we gauge whether this is important to them?*"

There will probably be different perspectives from different "users" on the questions which could be asked, and the best use of the answers provided, and this is why welfare assessments of animals, including poultry, will suffer from: "*You can please some of the people all of the time, you can please all of the people some of the time, but you can't please all of the people all of the time*" (Lydgate, 1370—c. 1451).

6.3 What poultry OBMs are people measuring and how?

I have chosen to illustrate how poultry OBMs are now being used by reference to three poultry assessment systems: Welfare Quality® (2009a), Assurewel (2016), and AWIN Animal Welfare Indicators (2015).

6.3.1 *Welfare quality*

Blokhuis et al. (2003) proposed that a wide range of measured criteria were likely to be required to provide a practical assessment of welfare on farm, and the Welfare Quality (WQ) project stemmed from this idea. In the WQ project (www.welfarequality.net) (Welfare Quality Protocols, 2009a,b,c) over 30 institutes from across the EU came together to allow animal and social scientists to work together to outline the areas of animal welfare concern, and then to create an assessment system—a set of measures which could be used on the farm and at the slaughterhouse for a range of health, behavior, injury, disease, comfort, feeding, management, human–animal interactions, emotional state and housing factors which can affect animal welfare (Blokhuis et al., 2003; Botreau et al., 2007a,b, Veissier et al., 2008). The Welfare Quality scientists identified 4 principles (good feeding, good housing, good health, appropriate behavior), and stemming from these 12 criteria the animal-based measures that address aspects of the welfare state of the animals (see Tables 6.1 and 6.2).

The measures which were finally chosen to be used were, in the majority, derived from established research methods already described in the literature. An example is feather cover scoring for laying hens. Hughes and Duncan (1972) and Hill (1980) proposed general scoring systems, which could be used to assess plumage of the whole body of the bird. Fölsch et al. (1980) and Grashorn and Flock (1987) used planimetry to estimate the extent of defeathered areas. Adaptations of these assessment methods were used to score different areas of the plumage by Meunier-Salaün (1983), Tauson (1984) and Gunnarsson et al. (1995). Tauson (1984) found that there was good observer reliability when using a 1–4 point scale on five body parts of the hen.

Tables 6.1 and 6.2 show the "hierarchical" structure of the measures proposed in the Welfare Quality system for laying hens and broiler chickens. Where possible an OBM was proposed, however, when no OBM was available, or when such a measure was not found to be sensitive or reliable enough when used in practical farm assessment, RBMs were used. This is consistent with the general consideration that where appropriate, both RBMs and OBMs should be used to provide as much information for the assessment of animal welfare as possible. The WQ assessment measures were evaluated with respect to their validity (that they assess aspects of the actual welfare of animals), reliability (that they have acceptable inter or intra observer repeatability and are robust to external factors such as time of day or weather conditions) and their feasibility of measurement.

Table 6.1 Collection of Welfare Quality data for laying hens on farm (Welfare Quality Protocol, 2009c)

Principle	Welfare criteria		Measures
Good feeding	1	Absence of prolonged hunger	Feeder space
	2	Absence of prolonged thirst	Drinker space
Good housing	3	Comfort around resting	Shape and total length of available perches, evidence of red mites, dust sheet test
	4	Thermal comfort	Panting, huddling
	5	Ease of movement	Stocking density, perforated floors
Good health	6	Absence of injuries	Keel bone deformation, skin lesions, foot pad dermatitis, toe damage
	7	Absence of disease	On farm mortality, culls on farm, enlarged crops, eye pathologies, respiratory infections, enteritis, parasites, comb abnormalities
	8	Absence of pain induced by management procedures	Beak trimming
Appropriate behavior	9	Expression of social behaviors	Aggressive behaviors, plumage damage, comb pecking wounds
	10	Expression of other behaviors	Use of nest boxes, use of litter, enrichment measures, free range, cover on the range, covered veranda
	11	Good human–animal relationship	Avoidance distance test (ADT)
	12	Positive emotional state	Novel object test (NOT), qualitative behavior assessment (QBA)

The measures described in the WQ protocols are made on farm, or sometimes in combination with measures made at the slaughterhouse. An example is skin or feather lesions, where the measures can be made on farm but can also, and on more birds, be made at slaughter. The data collected according to the WQ protocols can be aggregated (mathematically combined) to calculate a "criterion-score," which is a combined score for the measures under a specific criterion heading. For example, under the heading "*absence of injuries*," the measures (1) keel bone deformation, (2) skin lesions, (3) foot pad dermatitis, and (4) toe damage would be aggregated.

The scoring formulas required for this aggregation process were created by consultation with groups of experts from animal sciences. Weighted sums were calculated to enable a farm to be given an "overall welfare score" based on the data collected on the individual measures (Botreau et al., 2007a,b) described in Tables 6.1 and 6.2. It is then theoretically possible to combine the scores for each

Table 6.2 Collection of Welfare Quality data for broiler chickens on farm (Welfare Quality, 2009c)

	Welfare criteria		Measures
Good feeding	1	Absence of prolonged hunger	This criterion is measured at the slaughterhouse
	2	Absence of prolonged thirst	Drinker space
Good housing	3	Comfort around resting	Plumage cleanliness, litter quality, dust sheet test
	4	Thermal comfort	Panting, huddling
	5	Ease of movement	Stocking density
Good health	6	Absence of injuries	Lameness, hock burn, foot pad dermatitis
	7	Absence of disease	On farm mortality, culls on farm
	8	Absence of pain induced by management procedures	This criterion is not applied in this situation
Appropriate behavior	9	Expression of social behaviors	As yet, no measure is developed for this criterion
	10	Expression of other behaviors	Cover on the range, free range
	11	Good human–animal relationship	Avoidance distance test (ADT)
	12	Positive emotional state	Qualitative behavioral assessment (QBA)

measure (criterion scores) to calculate principle scores, and then to combine the principle scores (under the headings good feeding, good health, good housing, appropriate behavior) to make a *single welfare score for the farm*. The scores obtained by the farm using these measures can then be used to assign that farm to a welfare category:

Excellent: the welfare of the animals is of the highest level.
Enhanced: the welfare of animals is good.
Acceptable: the welfare of animals is above or meets minimal requirements.
Not classified: the welfare of animals is low and considered unacceptable.

The ambition of this "aggregation"—the bringing together of scores for a number of individual measures into one final score—was that this offered the possibility to create a single welfare score for a farm that could have a possible use in farm assurance, and even as the basis for a future "welfare labeling scheme" (Botreau et al., 2009; Rushen et al., 2011). After a farm assessment, the results for individual measures could be fed back to the farmer. By combining RBMs with OBMs, the potential exists to provide a tool for informing the farmer of the welfare status of his animals, to enable him to see how he compares to other farms, and also to support improvements and management decisions. While it is possible to combine all measurement results to give an aggregated overall score, no commercial assurance scheme has attempted (yet) to give single welfare scores to farms—however, the assessment methods and protocols described in the WQ system have been widely used and adopted in part (individual or grouped measures) into a very large number of research studies, and also to a degree into farm assurance inspection processes (e.g., see Heath et al., 2014; de Jong et al., 2016; Tuyttens et al., 2015).

Of course, the time required to perform an assessment is an important consideration when incorporating WQ measures into farm assurance programs. de Jong et al. (2016) studied the potential for reducing the time it takes to complete the WQ broiler assessment protocol using data from 180 flocks assessed on-farm and 150 flocks assessed at the slaughter plant. These authors assessed whether prediction of gait scores using hock burn scores could result in a simplification in terms of the time taken to record measures. Measurements of footpad dermatitis, hock burn, cleanliness and gait score on-farm were found to correlate with slaughter plant measurements of footpad dermatitis and/or hock burn, supporting substitution of on-farm measurements with slaughter plant data. A secondary analysis was performed using footpad dermatitis, hock burn, cleanliness and gait scores measured on-farm to see if these could be predicted from slaughter plant measurements of footpad dermatitis and hock burn. Close agreement was found between use of the full WQ protocol collected on farm, and with the simplification strategies. It was concluded that these simplification strategies could in principle reduce the time to complete the on-farm assessment by $\sim$1 hour (25% to 33% reduction) and strategy 2 could potentially reduce on-farm assessment time by $\sim$2 hours (50% to 67% reduction).

6.3.2 AssureWel

AssureWel is a collaborative project in the United Kingdom between the University of Bristol, the Soil Association and the RSCPA, with links to European farm assurance companies. The main aims of AssureWel were (and are) to integrate OBM assessment into the framework of existing farm standards and into commercial farm assurance schemes. It was carried out between 2010 and 2016, and was supported by the Tubney Charitable Trust. AssureWel worked to develop a system of welfare outcome assessments for the major farm animal species, which could practically be used in farm assurance schemes. The AssureWel project had the following aims: to develop training in welfare outcome assessment for vets, advisers and inspectors and to encourage the use of welfare outcomes in other United Kingdom and European farm assurance schemes. AssureWel built on the background provided by a previous project, LayWel (2016), and also very much adopted the basis of the measures proposed in Welfare Quality. The project has had a planned progression, with laying hens the first to be covered in Years 1 to 4, dairy cattle starting in Year 2, pigs in Year 3, and broilers, beef cattle and sheep in Years 4–5. AssureWel methods have been "field-tested" within the Freedom Food and Soil Association Certification schemes (see below) on farms which operate these standards, and using assessment of OBMs to help determine compliance with the standards within these schemes.

AssureWel has identified some criteria as "core" measures, with a mixture of considerations including the validity of each measure, the robustness and repeatability, sample size requirements and practicality of assessment on-farm. In this way, the AssureWel measures represent to a degree a "practicalization" of the longer list of measures first proposed in Welfare Quality. The AssureWel core measures for laying hens are: *feather loss, bird dirtiness, beak trimming, antagonistic behaviors, flightiness, birds needing further care*, and *mortality*. See AssureWel (2016b) for online resources and scoring scales, and also see the discussion in section 6.3.1 above about studies on the effects of efforts to reduce the time taken to carry out welfare assessment, for example, in de Jong et al. (2016).

Pilot use on a large number of farms has shown that the AssureWel assessment of these core outcome measures, used as part of a visit, which is taking place for overall farm assurance purposes, takes around 10 to 15 minutes per farm for the sample sizes suggested. Sample size requirements are described as "*Some measures require an examination of the entire flock. For other measures a smaller sample of 50 birds needs to be assessed. However assessing a larger number of birds will increase the confidence of the sample and be more representative of the whole flock.*" The AssureWel protocols were designed to be used by "*anyone with relevant livestock experience—training is required to ensure reliable and accurate results, and this training is available through the AssureWel project.*"

The inclusion of a set of AssureWel measures into farm assurance schemes, or for use by companies, producer groups and veterinarians, may allow formal assessment and then feedback and benchmarking, which may help to improve farm management and general levels of hen welfare. AssureWel has, by its nature, been exploratory, and many findings on the most effective means to implement and incorporate OBMs into standards have been made as result of this hybrid between commercial implementation, welfare outcome standards and the inclusion of "welfare science" measures during practical farm inspection visits.

6.3.3 Animal Welfare Indicators Project (AWIN)

AWIN was an EU project (2011 to 2015) (AWIN, 2015) which addressed the development, integration and dissemination of OBMs, with an emphasis on pain assessment and pain recognition and with a particular focus on species not already addressed in the Welfare Quality project. Of particular interest in respect to this chapter is the novel and innovative work on turkeys.

Work package 1 of AWIN developed science-based welfare assessment protocols and supported the use of these protocols through interactive apps to facilitate data collection, data storage and data analysis. The AWIN project adopted the principles and criteria used in Welfare Quality, and had these measures tabulated in the Welfare Quality format (see Table 6.3).

A development within the AWIN protocol is the use of transect walks to collect the data. For turkey welfare assessment, these consist of standardized movement through the house along randomly set paths, which cover the full area of the house (Marchewka et al., 2013). For this method, the assessor walks along a

Table 6.3 Tabulation of the welfare indicators proposed by the AWIN project for turkeys (AWIN, 2015)

Principle	Welfare criteria		Measures
Good feeding	1	Absence of prolonged hunger	Small size
	2	Absence of prolonged thirst	Small size
Good housing	3	Comfort around resting	Dirtiness
	4	Thermal comfort	Featherless
	5	Ease of movement	Not available (no measure proposed)
Good health	6	Absence of injuries	*Head wounds, back wounds, tail wounds*
	7	Absence of disease	Immobility, lameness, small size, sick, terminally ill, dead
	8	Absence of pain	Lameness
Appropriate behavior	9	Expression of social behaviors	Aggression towards flockmate, featherless, mating, *head wounds, back wounds, tail wounds*
	10	Expression of other behaviors	Not available (no measure proposed)
	11	Good human−animal relationship	Not available (no measure proposed)
	12	Positive emotional state	Not available (no measure proposed)

Note that measures head wounds, back wounds, tail wounds occur in two criteria areas (absence of injuries and expression of social behaviors).

predetermined line (a transect) in the poultry house at a pace of 1 step per second along the transect to prevent “major disturbance” of the birds. During the walk, the assessor scores a number of visible indicators in a zone covered by a semicircular half oval, 3 m in diameter, imagined as the “assessment area” as the assessor walks forward through the birds (see the AWIN, 2015, protocol for a full description of the method). The following indices are recorded for turkeys (Table 6.3) —small size, head wounds, immobility, birds which are visibly sick, aggression towards a mate, dirtiness, back wounds, lameness, terminally ill, mating behavior, featherless, tail wounds, and dead. The use of the transect offers the potential for time efficient analysis of welfare outcomes in turkey flocks, and we await the publication of findings which show further results of research and commercial application of this method.

As mentioned in the introduction, and in common with other use of OBMs, those described in AWIN examine "what can be measured on farms" rather than assessing what "birds could or would do given the opportunity," and are not able to address some areas at all (expression of behaviors, human animal relationship) and so do not cover the fuller (more holistic) range of things which can, and do, or could, influence the animals' experience of a farmed life.

6.4 Are farm standards which include OBMs actually being implemented?

When a new method for assessment is proposed, for example, the WQ system, AWIN or AssureWel—four basic questions quickly emerge:

1. Is it practical (how long will it take, how much will it cost?)
2. Does it tell you something "real" about the animal's welfare (is it valid?)
3. Can two or more assessors give the same answer or score when assessing the same animal (is it repeatable?)
4. Are the measures influenced by weather, season, time of day, etc. (are they robust?)

Farm standards are inspected against by assessor/auditors/inspectors, who are usually trained (and sometimes licensed by government, e.g., in the case of organic inspectors). These inspection personnel usually visit the farms at intervals of between 12 and 18 months (dependent on the scheme) and inspect the premises, the records, and examine the animals against the requirements of the written standards. In the EU, many of the farm assurance schemes operate their assessments to fulfill the requirements of two ISO standards—ISO/IEC 17065 (ISO, 2016) (Conformity assessment, Requirements for bodies certifying products, processes and services) and ISO/IEC 17020 (Conformity assessment; Requirements for the operation of various types of bodies performing inspection). The "quality" of the inspectors and inspection process (in terms of repeatability and interassessor reliability) is critical if the process is to be considered impartial, sensitive and seen by the producers to be applied "fairly and justly" (Presi and Reist, 2011; Rushen et al., 2011). This is particularly the case for the use of OBMs, where the judgment of the assessor who visits a farm may differ from the opinion of the farmer (*you think my chickens are too dirty, I don't agree*). Therefore, work to provide confidence in the assessment process and the repeatability of assessment measures has been a central focus of much of the research carried out around use of OBMs (e.g., see de Jong et al., 2012a,b, 2016; Forkman et al., 2009a,b,c; Gocsik et al., 2016; Tuyttens et al., 2015).

To illustrate these points, it is probably useful to give some examples of standards which are particularly relevant to specific systems for laying hens—as it has proved to be very difficult to make a "one standard fits all" scheme for laying hens because of the diversity of production and management systems. Farm assurance overlying industry-led "standard" requirements, sometimes (but not always) within a legislative framework, is now the basis of much of the implemented assessment of laying hen production in the EU, and in some other parts of the world including the United States, Canada, and Australasia. This is probably because the poultry industries in these countries were first in the farming sector to adopt integrated business models (where the company acts as part of a feed, rearing and marketing business) as well as to adopt quality assurance standards, which sometimes include specific aspects regarding animal welfare. There are a number of commercial industry standards, which give the producer the capacity to sell to specific retailers or marketing groups that require compliance with a "standard." Compliance is therefore effectively a gateway requirement for the sale of products, and this gateway requirement is the financial and structural incentive for producers to be scheme members to sell eggs and poultry products. Some examples of these kinds of schemes in the United Kingdom that have welfare requirements and use OBMs in their standards are the British Egg Industry Council Lion Code, the RSPCA Freedom Foods program, and the Soil Association Certification.

The British Egg Industry Council (BEIC) "Lion Code" has 700 auditable criteria covering health, health planning, housing, space, feeder, drinker, health screening, humane culling, stockman inspection requirements, record keeping, and recording of medicine use. There has been a shift in the last few years to now include assessment criteria, which are more clearly animal welfare focused, with some of those criteria relying on OBMs. An example of an animal welfare OBM in this program is a requirement to record culls and mortality. Nearly 90% of UK eggs are now produced within the BEIC scheme, and since November 1998, 130 billion Lion eggs have been sold, and more than 50,000 independent audits have been undertaken.

The Freedom Foods Laying Hen Standard is a commercial activity of the Royal Society for the Prevention of Cruelty to Animals (RSCPCA, United Kingdom) which operates alongside the charitable animal welfare activities of the RSPCA. The laying hen standards (RSPCA, 2016) are created by the farm animal and science departments of the RSCPA charity, in association with industry and consumer stakeholders. The RSPCA says that the laying hen standards were created through the combined "*Knowledge of farming industry representatives, veterinarians, and animal welfare and production research scientists; gathered, discussed and taken into account; through standards technical advisory groups and wider consultation groups.*"

The RSPCA standards include many clauses which are significantly above legal baseline requirements, some "aspirational" recommendations, and, recently, the introduction to the scheme of OBMs. An example of a figure from the assessment protocol contained within the Laying Hen Standard (RSCPA, 2016) can be seen in Fig. 6.1.

Soil Association Certification (Soil Association, 2016) has a focus on organic farming, with the stated aims of avoidance of routine use of pharmaceuticals and vaccines, which is seen by many consumers as a logical fits with their aims towards "clean, green and ethical" systems of livestock management. The Soil Association standards for laying hens now incorporate clauses which are welfare focused, and also which require a degree of assessment of the impact on the animals, for example, requiring that records be kept of mortalities and causes of death, hock damage, and reject percentages.

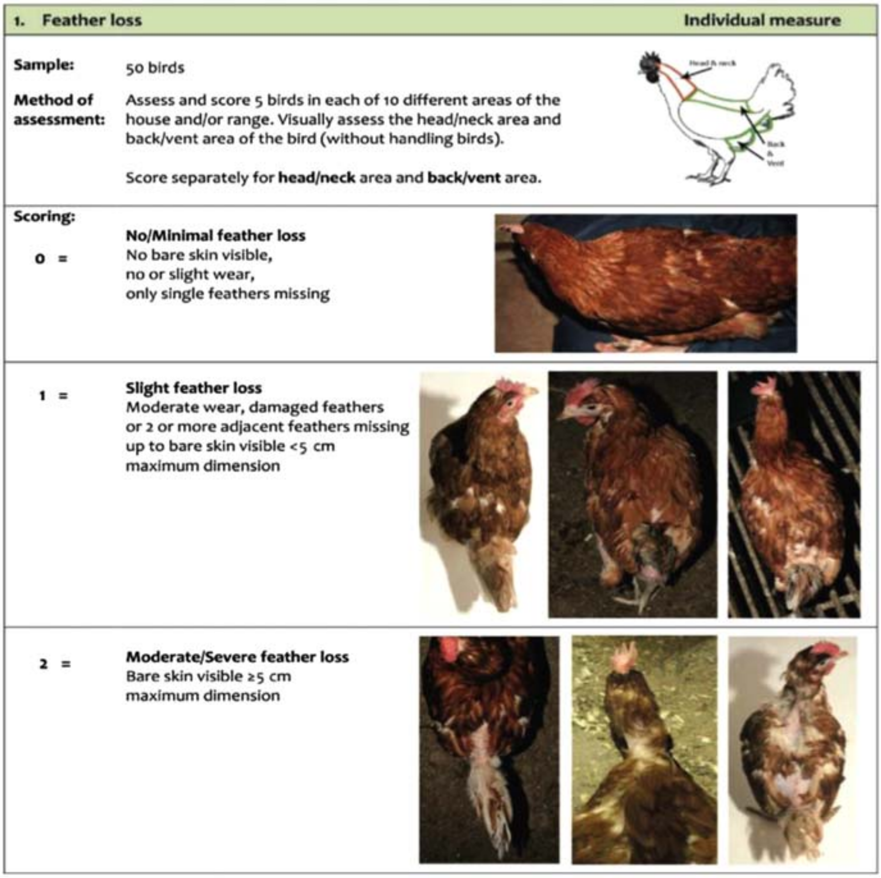

Figure 6.1 The feather loss assessment and scoring scale from the assessment protocol contained within the RSPCA Laying Hen Standard (RSCPA, 2016).

6.5 What do governmental bodies and commercial users think about the use of "outcome measures" in farm standards and farm assurance?

The European Food Safety Authority (EFSA, 2012), in a report on the use of animal-based measures to assess the welfare of animals, concluded that "Animal-based measures are the most appropriate indicators of animal welfare and a carefully selected combination of animal-based measures can be used to assess the welfare of a target population in a valid and robust way." However, they went on to state that, "in some situations, feasibility and economic aspects may be most important, whereas in others sensitivity and specificity may take priority" and that "the systematic collection of standardized field data on animal-based measures and subsequent storage in well-defined databases can in the future assist in better assessing the validity and robustness of animal-based measures and thus the move towards quantitative risk assessment of animal welfare. Such data are also a potentially valuable tool to monitor animal welfare in Member States." Their recommendations included:

- Both animal-based measures and input factors (resource- and management-based measures) should be used in combination when monitoring animal welfare.
- Once a long list of valid and robust animal-based measures has been identified, a shortlist should be defined in consultation with a diverse group of stakeholders.
- There should be on-going evaluation of animal-based measures and how they are used to assess the welfare of animals as this is a rapidly expanding area and new measures and new methods of recording established measures are being developed.

But what do farmers actually think about the use of OBMs and what are some of the potential problems associated with these kinds of assessment schemes? Some recent focus group interview work by Buller and Roe (2009) found the following concerns voiced:

1. Who carries the cost of assessing OBMs?
2. How will they work in terms of periodicity and seasonality of assessment?
3. Difficulties (time, money, and the accurate identification of causes of failure) of achieving compliance.
4. Potential for mistrust, amongst producers and others, of the pertinence of certain animal behavior assessments.
5. Can reduction of specific animal-based assessments to a single farm-based algorithm actually give a meaningful "single score" which is useful to producers, retailers and advisors?
6. The difficulty of employing OBMs in conveying "positive" information to consumers as most OBMs are based on potentially negative characteristics (injuries, hunger, avoidance, etc.)

6.6 Conclusions and implications

There has been a shift in perception of what constitutes effective assessment in farm assurance settings, and a recognition that OBMs can provide valid indicators of animal welfare, as welfare is a characteristic of the individual animal, not just of the system in which animals are kept. The sorts of questions which are being asked are:

Are the animals properly fed and supplied with water?
Are the animals properly housed?
Are the animals healthy?
Can the animals express a range of behaviors and emotional states?

A multipronged strategy involving various RBMs and OBMs is recognized as being most likely to provide the capacity for comprehensive welfare monitoring of farm animal welfare. Such a strategy may include regularly updated species care guidelines, accreditation standards, longitudinal, multidisciplinary and multi-institutional studies, and rapid assessment tools for continuous welfare monitoring. Organizations which carry out farm inspection for retailers and for government have started to use animal welfare OBMs, including physical condition and lesion scoring, as a progression from RBMs in their inspection work.

At present, the use of OBMs in the commercial setting and on a significant scale outside of controlled studies and for a realistic period has not taken place. Animal-based measures are, in general, complementary to existing frameworks until proven otherwise. Thus, if the use of OBMs in commercial assessment systems can be initiated, most likely in collaboration with existing certification and assurance bodies, then it will be possible to determine whether the claims that OBMs offer real value to the consumer and producer are realistic. The consumer could potentially benefit, through choice backed up by product information (and potentially labeling), and the producer may benefit by finding that he/she can make better, more "informed" management decisions.

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Poultry welfare assessment on the farm: Focusing on the individual

7

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7.1 Introduction

Animal welfare assessment and post-assessment decisions are made within the complexity of issues involving ethics, science, veterinary medicine, economics, and policy. Animal welfare itself is complex and it is best understood by considering its three components: biological functioning, affective states, and opportunities for natural living (Fraser et al., 1997). We find it useful to employ all three of these components when assessing poultry welfare. Training and experience are keys to carrying out a practical, accurate, and informative assessment.

This chapter is designed to review practical issues related to the assessment of the welfare of compromised individual birds in a poultry flock, as well as their treatment or euthanasia. Assessing individual birds is easier in small flocks of up to 100 birds. In larger flocks, individuals may be overlooked. It takes time and a trained eye to identify individual deviations from normal, and it takes a systematic approach to find the affected individuals.

Compromised birds can most readily be recognized by their behavior and appearance. The use of behavior in the assessment of health at the flock level was covered in a previous publication (Linares and Martin, 2010). The natural social structure within flocks is expressed and governed by competition for resources, breeding behaviors, parental care, aggressive and submissive behaviors, pecking orders, and synchronized behaviors (Estevez, Chapter 12). The presence, absence, frequency, and intensity of these behaviors are some of the parameters used for the assessment of poultry welfare. An individual bird's welfare depends on its ability to cope with this natural social structure, the environment, management practices, and the overall health status of the flock. Sickness and injury can impair an individual bird's ability to cope.

This chapter is focused mainly on chickens as they are the most abundant and the most studied poultry species. It will cover the following topics:

- Behavior of compromised birds
- Identification of sick or injured individuals
- Decision-making regarding whether to treat or euthanize
- Humaneness and practical considerations for on-farm euthanasia methods

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7.2 Behavior of birds that are in pain or ill

The popularity of small scale chicken rearing, particularly for egg production, is generating greater awareness of the complexity of chicken behavior and creating emerging demands for individualized care. At the same time, commercial egg and poultry production systems rely on making population-based decisions for flocks that comprise thousands to hundreds of thousands of birds. Collection of flock-based performance outcomes, such as feed and water disappearance, growth, egg production, mortality, and morbidity, are key business metrics that also provide basic tools to assess poultry welfare at the flock level (Butterworth et al., 2011). These performance data are helpful for flock-based interventions and identifying risk factors and preventive interventions for subsequent flocks, but even in a flock that is healthy overall individual birds can be experiencing welfare problems.

Detecting and treating welfare problems at the individual level are challenging, and yet impacts can be high with respect to the severity and duration of suffering experienced by the affected birds. In complex environments, individual birds have flexibility to act on their preferences, to interact with resources, to seek comfortable microclimates, and to avoid unpleasant situations. In doing so, there is the potential for birds to improve their own welfare. Opportunities to satisfy needs may be more limited in commercial environments due to space, resource availability, and social grouping, but commercial system designs continue to evolve to satisfy species typical behavior such as perching, nesting, foraging, and dustbathing. Despite these advances, vulnerable individuals that fail to thrive can emerge within a flock in any system for multifactorial reasons, including social rank, mobility, illness, and injury (Butterworth and Weeks, 2010). How do we identify these birds and what do we do about them?

The economic realities of commercial egg and poultry production can include bird to caregiver ratios of 100,000:1 or greater. In these situations, time constraints are imposed such that only a fraction of a second is available for daily inspection of individual birds. When compromised birds are identified, individual animal treatment is often limited to euthanasia. However, casual observations on commercial egg operations by one of the authors (Millman) reveals that some caregivers are implementing creative approaches to move compromised birds that are injured, ill, or failing to thrive into "close up" pens for easier, more frequent inspections, while others are utilizing individual or low-density hospital cages that provide birds with the opportunity to recuperate, rehydrate, and replenish nutrients before decisions are made about returning the bird to the flock or euthanasia.

7.2.1 *Pain-related behavior*

Pain associated with trauma or disease negatively impacts the welfare of individual birds to differing degrees and can be difficult to observe in chickens (Gentle, 2011). Acute pain occurs over seconds or days, as a result of minor trauma or stimulation of nociceptive receptors, and ceases upon healing. Chronic pain occurs over weeks, months, or years as a result of major trauma or chronic disease states, such as lameness, with subsequent pathological changes in the peripheral nervous system, spinal cord, and brain. Research suggests that there is conscious pain perception by chickens, as shown by pain coping behaviors such as one-legged standing and sitting by lame broilers (Gentle and Corr, 1995), and increased activity and improved gait scores when lame broilers are provided with analgesia (McGeown et al., 1999). Furthermore, broilers display reduced pain responses when distracted by other behaviors that they are motivated to perform, such as feeding, suggesting changes in pain transmission and peripheral inflammation that produce marked hypoalgesia or even complete analgesia (Gentle and Tilston, 1999; Gentle, 2001).

Chickens may display active avoidance and escape responses to acutely painful stimuli, but paradoxically may also display crouching immobility with no outward signs of pain (as reviewed by Gentle, 2011). For example, initial feather removal when birds are feather-pecked by flockmates results in agitation, wing flapping, and vocalization, suggestive of pain (Gentle and Hunter, 1990). Prolonged periods of injurious feather removal often result in the recipient bird crouching immobile in what may be an evolved antipredator or learned helplessness response. During this immobility, electroencephalogram (EEG) frequency readings are similar to those that occur during sleep, tonic immobility, and analgesia, suggesting that pain experienced during the latter stages of injurious feather pecking may be attenuated (Gentle and Corr, 1995). However, this immobility response poses particular challenges for affected individuals within confined environments, where social facilitation and trauma are likely to attract the attention of nearby birds and amplify injurious pecking behavior. Removal of the affected bird into a hospital pen or cage is warranted to provide protection from further injury and an opportunity for recuperation.

In addition to possible causal effects, housing and management factors can exacerbate or ameliorate pain experienced by injured or diseased birds. Nociceptors present in the scaly skin of the feet suggest that conditions such as footpad dermatitis and bumblefoot are likely painful (Gentle, 2001). Broilers with footpad dermatitis were quicker to lie down than sound birds, and this response was ameliorated by nonsteroidal anti-inflammatory drugs, such as carprofen and meloxicam (Hothersall et al., 2016). However, carprofen was not found to affect walking speed or gait patterns in another study, suggesting some gait abnormalities may be associated with challenges due to kinematics rather than direct associations with pain (Corr et al., 2007). In the laying hen industry, keel bone fractures are common although their incidence varies across countries and genetic lines (Harlander-Matauschek et al., 2015; Toscano, Chapter 8). Hens with keel fractures were reluctant to move from perches, with delayed latency to land especially at greater perch heights (Nasr et al., 2012a, 2015), and this effect was ameliorated by an analgesic drug (Nasr et al., 2012b). Furthermore, hens with keel fractures preferred locations within the pen where they previously received the analgesic drug, whereas this location preference was not displayed by hens without fractures (Nasr et al., 2013). Pain management through drugs such as carprofen, meloxicam, and butorphanol is unlikely to be a practical intervention in commercial environments due to cost as well as the lack of necessary approvals in some countries for their use in poultry raised for meat and egg consumption. In the United States and other countries, aspirin is approved for use in poultry as an aid in reducing fever and for mild analgesia. A common use of aspirin is in breeder birds after oil-based inactivated vaccine injections. Aspirin reduces the fever and localized pain that can be associated with these injections, particularly as breeder birds receive multiple injections at a time.

The welfare of injured birds can be improved with interventions that target mobility problems. In noncage systems, for example, perches and water drinkers can be provided at heights that are easily accessed, minimizing the need for birds to stretch and jump. Ramps for hens to navigate between litter areas, nests, and tiers reduce the need for flying and jumping, and make it less likely that hens will be trapped in litter areas overnight. Comfort when lame birds are housed on wire may be more difficult to provide due to complications with hygiene when alternative surface materials are provided.

7.2.2 Sickness behavior

In addition to pain, inflammation and illness result in changes in physiologic, behavioral, and neuroendocrine systems that may reduce the likelihood of predation or conflict with other members of the flock (Hart, 1988). Sleep and thermoregulatory behaviors are important components of sickness behavior, positively associated with recuperation from bacterial infections (Toth et al., 1993). A cascade of proinflammatory cytokines, such as IL-1, IL-6, and TFN-α, is produced by myeloid cells in response to infection, such as the presence of lipopolysaccharide (LPS) endotoxin. These cytokines produce the typical clinical signs of illness in chickens (see below), including lethargy, reduced appetite, ruffled feathers, reduced preening, thermoregulatory behavior, and activity. Hyperthermia, increased corticosterone, increased drowsiness, and reduced feed intake in an operant food reward task were displayed by chickens in response to LPS challenge (Johnson et al., 1993a). Sickness behavior is an active process rather than a consequence of disease. For example, data loggers implanted in free-ranging kudu revealed that activity decreased during febrile periods to 40% of activity observed when the animals were afebrile. Furthermore, the animals appeared to seek warmer microclimates on febrile days (Hetem et al., 2007).

Sickness behavior is organized as a motivational state (Aubert, 1999), and consequently expression of sickness behavior by an individual will vary according to context and competing motivational factors. For example, effects of LPS injection on song sparrows were found to be much less noticeable during the breeding season than other times of the year (Owen-Ashley and Wingfield, 2006), and expression of sickness behavior differed when zebra finches were kept in isolation rather than in a colony (Lopes et al., 2012). When housed in a research facility, Pekin ducks displayed anorexia and elevated thermal responses when challenged with bacterial and viral pathogens, but changes in activity were not observed due to the limited complexity of the barren pens in which they were housed (Marais et al., 2013). Using a cross-over experimental design, laying hens were observed to display more marked sickness behavior responses following LPS challenge when they were housed in free-range conditions than when they were housed in commercial cages. Relative to saline treated birds, LPS-induced sickness was associated with 53% reduction in walking, 60% reduction in preening, 86% reduction in roosting, and 147% increase in sleeping for hens housed in free-range conditions providing greater opportunities for caregivers to recognize sick birds. Interestingly, expression of sickness behavior was also influenced by previous experience with free range and cage housing environments during the pullet and early lay phases of production (Gregory et al., 2009). There is evidence that behavioral and physical responses of chickens to endotoxins are also affected by genetic strain (Cheng et al., 2004; Lieboldt et al., 2016).

Whereas sickness behavior responses may be evolutionarily adaptive at the species level, it is unclear if there are proximate benefits in captive environments. Nonsteroidal anti-inflammatory drugs, such as indomethacin (Johnson et al., 1993b; Zendehdel et al., 2015), aspirin, and celecoxib (Zendehdel et al., 2015) have been shown to attenuate pyrexic effects and sickness behavior in chickens, and have the potential to reduce discomfort and feelings of malaise. Opportunities for compromised animals to select thermal microclimates and isolation may facilitate rest and comfort. Compromised birds often congregate in secluded or protected areas within the house, such as adjacent to walls or amenities such as feeders (Butterworth and Weeks, 2010). It is unclear if these locations are selected as more comfortable microclimates, or because of social facilitation or avoidance of perceived threats or bullying. Further research examining sickness motivation in poultry would be helpful to inform caretaker inspection protocols and opportunities to facilitate recuperation.

7.3 Identification of sick or injured individuals

The health of a flock depends on factors such as their environment, nutrition, biosecurity, and immunity. Even in a thriving and healthy flock, individual birds may get sick or injured due to issues such as partial or poor immunity, congenital defects, trauma, and social structure. The impact of contagious diseases, environmental extremes, and management failures is relatively easy to identify and assess. Identifying a sick or injured bird while observing a healthy flock, particularly in a flock larger than a hundred birds, may not be as easy. Training the eye to look at groups of approximately 100 birds at a time, combined with transect walks (Marchewka et al., 2013, 2015), helps to identify affected individuals.

The appearance of a sick or injured chicken may range from alert and responsive to severely depressed. The bird's appearance will depend on the severity of the injury/disease. That severity will be exacerbated if the bird has difficulty accessing feed and water. In order to identify a sick or injured bird, the first observations are of appearance, posture, and locomotion. While active, a healthy chicken stands holding its head relatively high with round-shaped eyes, wings folded close to the body, tail held high and legs extended directly under the body (Fig. 7.1).

Figure 7.1 Normal appearance (chicken at the front center). Note the clean feathers, upright posture, the head held high, wings folded close to the body, and the tail held high [Linares picture].

Figure 7.2 Appearance of a severely sick or injured chicken. The bird is sitting with its head retracted into the body, the feathers are dirty, and the tail is held in a lowered position [Linares picture].

Preening behavior is common, and a healthy chicken's feathers look smooth and shiny. As chickens reach sexual maturity, their combs and wattles grow and turn reddish. The shanks and feet may be yellow or another color depending on the breed. Regardless of the color, the shanks should look supple and the scales clean and shiny. At the opposite end of health, a severely sick chicken tends to sit with its head drawn close to the body, eyes semiclosed or closed, and feathers ruffled and soiled (Fig. 7.2). As mentioned above, sick birds may separate themselves from

Figure 7.3 Subtle signs of sickness or injury (chicken at the front center). The head is retracted into the body, the wing is dropping slightly and the tail is held in a lowered position [Linares picture].

the flock and seek a place to hide such as a dark corner, or remain in a nest or enclosure while the other birds are active. Severely diseased and depressed birds may be unresponsive to external stimuli.

The range of appearances and behaviors from healthy to moribund may offer subtle to glaring clues to the observer (Fig. 7.3). Comb/wattle size regression and paleness may be indicators of injury or disease. Paleness or loss of pigmentation in the shanks may be an indication of parasitic disease. Overall skin paleness may be an indication of anemia. Some breeds do not deposit yellow pigment on their shanks so overall yellowness to the skin may indicate jaundice due to liver damage. Darker than normal comb, wattles and shanks with dry skin are an indication of dehydration. Dark purple comb and wattles could be due to hypoxia/cyanosis resulting from cardiac or respiratory deficits.

In a flock composed of birds of the same age and breed, it's easier to observe birds that are trailing in size or weight. While some may be simply smaller than others, smaller/thinner birds could be failing to thrive due to injury or disease. Failure to thrive could deteriorate into emaciation and death. Other than disease or injury, congenital defects, such as a crossed beak, could lead to a failure to thrive. A crossed beak chicken may grow and develop normally until the beak grows to the point that it begins to impair feed consumption. Feathers may preclude the observation of weight loss until it is too late. Small and/or weak birds should be palpated to determine the extent of muscle mass loss. Some conditions, such as chronic oviduct infection (salpingitis) in hens, could provide multiple indications of disease such as comb/wattle size regression, emaciation and a large hard abdomen due to the chronic accumulation of organized caseous exudate in the oviduct.

A healthy bird responds to novel or threatening stimuli, such as a foreign presence, noises, or sudden bright lights or movements, as part of its fear response. As one approaches a healthy bird it may walk, run, or fly away. These normal avoidance behaviors can be used to identify a sick or injured bird in a flock. When walking among a flock in floor-type housing, the birds will typically move away clearing a path in front. A weak, sick, or injured bird may fail to move or move more slowly than the rest of the flock.

Lack of avoidance or slow avoidance could be caused by systemic, musculoskeletal, or nervous system diseases. Brain damage may result in clinical signs such as prostration, tremors, head tilt, and star-gazing posture. Peripheral nerve damage may result in partial or complete paralysis. Injury or disease may alter normal stance and locomotion. A chicken with unilateral leg paralysis due to sciatic nerve damage caused by Marek's disease will sit with the paralyzed leg extended forward. A bird with a lumbar spine lesion due to spondylolisthesis (congenital) or vertebral osteomyelitis (infectious) may develop bilateral leg paralysis and will sit back on its hocks with both legs extended forward. Bilateral leg paralysis will force the bird to move backwards using its wings. A rooster may show decreased strutting and mating behavior due to lameness associated with bacterial arthritis or chronic swelling of the footpad, also known as bumblefoot. Musculoskeletal injuries or lesions in the legs may cause a noticeable limp and the bird may hold the affected leg off the ground for an extended period of time (Fig. 7.4). Close observation and palpation is required to determine if the lameness is due to bone, joint, or tendon issues. Lameness is detrimental to the welfare of individual birds as it impairs their ability to perform essential behaviors required to thrive within the flock (Weeks et al., 2000).

Figure 7.4 Bird holding foot off the ground. The foot is swollen (arrow) [Linares picture].

Injurious pecking can result in fresh or dried blood on the feathers, feather loss, abrasions, and lacerations. The location of the skin trauma could be indicative of the cause. Trauma to the toes may be associated with toe pecking in young poultry. Head and facial trauma in roosters is usually associated with fighting or male aggression. A sick or injured chicken can be the subject of injurious pecking by flockmates just because it looks or acts differently. Feather loss and trauma to the nape and back of a hen is associated with excessive male mating behavior. This type of trauma may be severe and lead to the hen's death. Excessive breeding may be due to male aggression or a hen that has neurological or musculoskeletal lesions that cause it to assume a posture resembling breeding receptiveness or lordosis. Body and tail feather loss could be associated with feather pecking. Severe feather pecking is related to feeding and foraging behavior (Rodenburg et al., 2013; Nicol, Chapter 9).

A hen can also be injured by vent pecking. When a hen lays an egg, it prolapses part of its vagina out of the cloaca. This can be accentuated by obesity or underlying disease. Sometimes, before a hen brings the exposed portion of the vagina back into the cloaca, another bird may become attracted to it and peck at it. The initial bleeding and subsequent swelling in the area of the cloaca could lead to the hen's death due to cannibalism or a wound-related infection. Vent pecking trauma may be hidden by feathers so it may be first spotted by the observation of blood on the eggshells.

A bird with respiratory issues may show one or multiple clinical signs such as head shaking, sneezing, coughing, gasping, and cyanosis. A bird with loose droppings or diarrhea may have a vent pasted with feces. A bird with kidney failure may have vent pasting with urates. As these conditions advance, the bird could assume the aforementioned severe illness posture and become unresponsive/comatose prior to death.

7.4 Decision-making regarding whether to treat or euthanize

Individual sick or injured birds within a flock must be promptly treated or euthanized. The decision to treat is best reached within the context of the veterinarian–client relationship. Individual bird treatment requires isolating the bird and monitoring its progress at least twice daily to reassess whether the bird is on its way to recovery or should be euthanized.

Euthanasia means to end the life of an individual animal in a way that minimizes or eliminates pain and distress. Experience and training are needed to recognize signs of pain, injury, illness, and distress that indicates that euthanasia may be necessary. As mentioned in the introduction, an individual bird's welfare depends on its ability to cope with its natural social structure, environment, management practices, and the health status of the flock. While assessing the welfare of an individual bird within the context of the flock, in addition to assessing the present situation one must also have foresight as to the consequences of the decision for not only the bird but the flock. The decision to euthanize an individual bird should be made without delay based on the following:

- Failure to respond to treatment
- Signs of chronic, severe, or debilitating pain and distress
- Inability to access feed and water
- Inability to stand or walk
- Marked weight loss/loss of body condition.

7.5 Humaneness and practical considerations for on-farm euthanasia methods

Once the decision to perform euthanasia is made, the method must be humane and conducive to being performed in a farm setting. Euthanasia should end life in a manner that is rapid and that minimizes pain and distress. The person performing euthanasia must be trained in the specific methods used at the farm level to ensure it is done properly, with respect, and is irreversible. The method used should result in rapid loss of consciousness followed by cardiac or respiratory arrest and, ultimately, a loss of brain function (AVMA, 2013).

7.5.1 Unconsciousness and death

There have been many scientific studies evaluating various euthanasia techniques to determine which are the most humane and practical methods for on farm use (Bader et al., 2014; Erasmus et al., 2010a; Gerritzen et al., 2004; Grandin, 1994). It's imperative for the method of euthanasia to be performed to cause rapid unconsciousness and death. Unconsciousness is when a bird becomes unaware or does not perceive sensation or feeling; therefore, no pain is felt (Lambooij and Hindle, Chapter 4). Studies have reviewed different euthanasia techniques for poultry to evaluate how quickly unconsciousness occurs, with instantaneous results being the most humane (AVMA, 2013; Bader et al., 2014; Erasmus et al., 2010a,b; Gerritzen et al., 2004; Gregory and Wotton, 1990; Woodbury et al., 1957). When a bird is unconscious, there is a lack of communication between the brain and the body but the neurons still fire, which causes convulsions occurring over several seconds that can be misinterpreted as conscious movement. Unconsciousness in poultry results in collapse, along with involuntary movement (tetanic spasms) occurring over several seconds.

Following unconsciousness, death should follow rapidly. Knowing what to evaluate to determine bird death is critical prior to disposal. Some forms of euthanasia, such gas, could potentially be reversible if not performed properly or administered for proper duration. Verification of death in a bird includes the complete absence of corneal reflex, lack of breathing, complete muscle relaxation without movement, and lack of a heartbeat (Erasmus et al., 2010a; Lambooij and Hindle, Chapter 4).

7.5.2 On-farm Euthanasia Methods

The AVMA (2013) published guidelines for the humane euthanasia of poultry after a careful review. These guidelines include approved methods based on scientific research, humaneness, and consistency with the veterinary oath. The veterinary oath states that a veterinarian must provide "protection of animal health and welfare, the prevention and relief of animal suffering . . .." The World Organization for Animal Health's (OIE) standards for animal welfare also include a well-reviewed chapter on killing of animals for disease control purposes (OIE, 2016). The OIE chapter includes reviews of various poultry euthanasia methods in the context of mass depopulation, but we have chosen to use the AVMA guidelines as our main reference as they are more applicable to individual bird euthanasia.

When determining which euthanasia method to use, the environment, surroundings, and age of the bird must be considered. Assessing the number of birds to be euthanized is also an important consideration. Advance preparation prior to performing euthanasia should include assessing the environment where euthanasia will be performed and identifying any tools necessary for rapid euthanasia. Different precautions or techniques may be preferred depending on whether the bird is in a floor, cage, or free-range environment.

In the AVMA guidelines, a method of euthanasia is considered acceptable when it can consistently produce a humane death when used as the sole means of euthanasia. A method is considered acceptable with conditions if the method requires certain conditions (e.g., related to operator training) to consistently produce a humane death. The only method of poultry euthanasia considered acceptable without conditions by the AVMA is the use of injectable anesthetics (AVMA, 2013). However, poultry euthanized by this method cannot be used for food, may not be suitable for postmortem diagnostics and present disposal issues due to the risk of secondary exposure of nontarget species due to residues.

Methods considered by the AVMA (2013) as acceptable with conditions include inhaled agents, cervical dislocation, decapitation, manually applied blunt force trauma, electrocution, gunshot, and captive bolt. These different methods of euthanasia cause death by two basic mechanisms: hypoxia and physical disruption of brain activity. In chickens, hypoxia and physical disruption of the brain are the most common mechanisms used. Hypoxia typically only results when a gas method is used as a result of the replacement of oxygen, such as with carbon dioxide (CO_2). Physical disruption of brain activity typically occurs after blunt trauma to the head, such as with captive bolt (Erasmus et al., 2010b).

After considering the AVMA conditions for acceptability and the practicality and safety of the aforementioned methods, in the remainder of this chapter we review gas inhalation, cervical dislocation, and captive bolt as the most suitable methods for on-farm euthanasia.

7.5.2.1 Gas euthanasia

Gas euthanasia is most commonly used to euthanize birds in hatcheries and commercial layer facilities, and less so on broiler, broiler breeder, and turkey farms. Gas euthanasia is typically performed in a tightly sealed box or compartment (Fig. 7.5) that contains the gas without leaks. It can take several minutes for death to occur after some initial agitation and involuntary movement (paddling legs and flapping wings). When a bird is very sick or has labored breathing, there may be more agitation during the initial exposure to the gas (Gerritzen et al., 2004; Smith and Harrap, 1997).

CO_2 is the most common gas used (Gerritzen et al., 2004); however, carbon monoxide (CO) and nitrogen gas could also be used. Varying concentrations of CO_2 are used to euthanize poultry, but typically chicks require a higher concentration than adults (Gerritzen et al., 2004; Woodbury et al., 1957). CO_2 is an ideal gas for on-farm euthanasia because it is available in compressed cylinders and is nonflammable and nonexplosive. It also has a high safety margin for humans.

Generally it is best to prefill the compartment with the gas prior to placing the birds inside and then gradually increase the gas concentration until death occurs. As previously mentioned, it is critical to ensure that death has occurred prior to disposal or burial because gas unconsciousness can be reversed if the bird has not been exposed to high enough concentrations for a sufficient period of time (Woodbury et al., 1957).

Figure 7.5 Gas euthanasia box.
Source: Courtesy of Cobb-Vantress, Inc.

Figure 7.6 Manual cervical dislocation (left, center) requires proper restraint of the chicken by the legs or wings. The neck should be grasped between 2 fingers and the head tilted up, then the head is rapidly pushed down. Mechanical cervical dislocation with a tool (right) can be used for larger birds.
Source: Dr. Ken Opengart, Keystone Foods.

7.5.2.2 Physical methods

Physical methods are a practical choice on the farm because they are rapid, virtually painless and, after proper training, easy to use (although some may find them aesthetically displeasing). When euthanasia is performed via a physical method, it is critical for the bird to be properly restrained during the procedure and personnel to be properly trained. The quickest and most humane on-farm AVMA-approved physical methods are cervical dislocation and captive bolt. Physical on-farm methods are deemed to produce immediate unconsciousness and a cessation of brain function due to disruption of the cerebral cortex.

Cervical dislocation

Cervical dislocation can be performed manually or mechanically and is a common method of on-farm euthanasia in the commercial poultry industry. Cervical dislocation may not cause immediate unconsciousness (AVMA, 2013). When cervical dislocation is properly executed, it results in rapid separation of the brain stem from the spinal cord via dislocation of the axis vertebra from the C1 vertebra. The jugular vein and carotid artery are also severed at the same time. The legs or wings of the bird should be grasped and the neck stretched in a very rapid motion by pulling on the head while applying a ventro-dorsal rotational force to the skull (AVMA, 2013; United States Poultry and Egg Association (USPEA), 2015). This should be done without crushing the brain, spine, or vertebrae (Fig. 7.6).

Before performing manual or mechanical cervical dislocation, the size of the bird should be considered. Proper manual cervical dislocation may be difficult for small chicks or very large birds. Manual cervical dislocation is a good method of on-farm euthanasia for small chickens and turkeys. Mechanical cervical dislocation uses a tool that results in luxation of the cervical vertebrae without primary crushing of bone (Fig. 7.7). This method is well suited for chicks and large birds.

Figure 7.7 Manual cervical dislocation of chicks requires adjustments based on their size, the inherent softness of their skeleton and delicate tissues. Using a mechanical device designed for this purpose (right) helps to execute proper cervical dislocation rapidly and consistently.
Source: Chick picture, Dr. Ken Opengart, Keystone Foods; Device picture, Maun Industries.

For large breeder chickens or turkeys, even with the mechanical method, assistance in handling the birds may be required to ensure that the correct angle and motion can be achieved for rapid euthanasia (Bader et al., 2014).

Captive bolt

A captive bolt is a device that is applied to the bird's head and which causes brain damage. This method can be used for large poultry that cannot otherwise be euthanized by cervical dislocation or one of the other methods. The most common captive bolt used for poultry is the nonpenetrating pneumatic bolt, but there are also other options. For example, a penetrating bolt can be used but may be more difficult to apply properly due to the small size of a chicken's head. An understanding of the anatomy of the head and brain are necessary for application. A captive bolt causes very rapid unconsciousness and death in chickens and turkeys (Erasmus et al., 2010b) (Figs. 7.8 and 7.9).

7.5.3 Trained personnel

Any person performing euthanasia must be properly trained in the specific method used, including specifics of how to perform the method, how to restrain the bird, the mechanism by which death occurs and how to verify and ensure death. Hands on training or observation should ideally occur often enough to ensure the euthanasia methods are being properly performed. During training, personnel should practice the method multiple times with someone who is experienced in the method of euthanasia. Training is a critical component to achieving rapid and humane on-farm euthanasia.

Figure 7.8 Examples of captive bolt devices. The pictures are of two models from Bock Industries. On the left is the TED, a cordless, gas canister device and on the right is the Zephyr-EXL, a hose connected pneumatic device.
Source: Bock Industries.

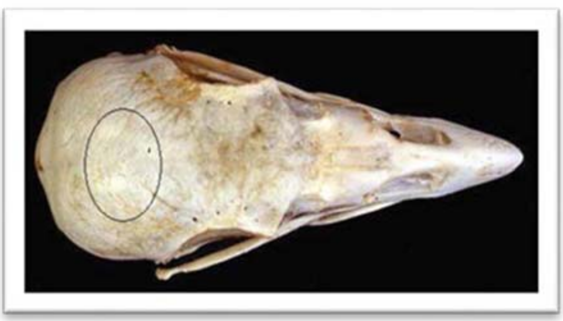

Figure 7.9 The captive bolt device should contact the brain in the area within the circle in the diagram above.
Source: Bock Industries.

7.6 Conclusions and implications

This chapter was designed to review practical aspects of the on-farm assessment of the welfare of individual birds in a poultry flock. When disease and injury cause individual birds within a flock to deviate from normal, their welfare is compromised. It is our responsibility to identify these compromised birds and take actions to improve their welfare.

In large flocks or commercial poultry operations it is common to practice population health with an emphasis on disease prevention rather than treatment. Treatment through medication is usually a flock-based decision when the health and welfare of the flock is at risk. In highly regulated production environments, there are fewer medications labeled or allowed for use in birds producing meat or eggs for human consumption. There is also increased demand by consumers for antibiotic-free production.

Isolating individual sick birds for treatment or recovery in a cage or pen, particularly those birds suffering from infections, is a potential biosecurity risk for the rest of the flock, since chronically infected birds could shed pathogens into the flock environment. However, scientific investigation and examination of the effectiveness of separate hospital areas for improving bird welfare and performance are needed to inform best practices. In addition, understanding the behavior of compromised birds, including where they are likely to be located within a house, has the potential to refine inspection techniques.

Because of the inherent low monetary value of individual birds in a large flock, there is little incentive for producers to invest in interventions to address injuries such as wound management, pain management, orthopedics, or surgery. The implication for most compromised individual birds at the farm is, therefore, euthanasia, and the decision to euthanize should be made without delay based on the following:

- Signs of chronic, severe, or debilitating pain and distress
- Inability to access feed and water
- Inability to stand or walk
- Marked weight loss/loss of body condition.

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Part IV

Continuing challenges

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Skeletal problems in contemporary commercial laying hens

8

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8.1 Introduction

Poor skeletal health has long been identified as a concern in laying hens, with initial observations in the 1930s (Warren, 1937). In the intervening period before the 1990s, when the vast majority of laying hens were kept in conventional cage systems, poor bone health was often attributed to lack of sufficient movement as well as increased egg production (Webster, 2004). Surprisingly, as noncage systems became more common in the 1990s and 2000s, particularly on the European continent, skeletal problems appeared to worsen, raising concern amongst many organizations and governments regarding ramifications for welfare and productivity (EFSA, 2015; FAWC, 2010, 2013). While the precise causes of skeletal problems are not clear, rearing is a critical stage of development which determines the quantity and quality of structural bone that will be present during the laying period. The following section provides an overview of skeletal development and influencing factors.

8.2 Pullet bone growth

8.2.1 *Skeletal development*

During rearing, two processes are responsible for bone growth—elongation, or longitudinal growth, and widening (Whitehead, 2004). The two processes are collectively referred to as endochondral ossification (Mackie et al., 2008) and are most studied in the appendicular long bones of poultry. Other bones that are particularly relevant for production and welfare problems, most notably the keel bone, have relatively few studies assessing their development in poultry, a topic which is addressed later. Following the period of development during rearing, bone continues to undergo remodeling in an effort to repair fractures or strengthen sections in response to applied forces. This process is driven by two types of cells: osteoclasts, which are responsible for the resorption, or removal, of old bone and unwanted cartilage, and osteoblasts, responsible for formation of new bone by depositing bone matrix (Florencio-Silva et al., 2015).

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Once fully developed, avian long bones resemble those of their mammalian counterparts, where an outer, compact cortical bone serves the principal structural role in combination with an inner trabecula or cancellous bone (Fig. 8.1). In contrast to cortical bone, the trabecular bone is less calcified, has a greater rate of bone remodeling, and plays a large role in metabolism (Seifert and Watkins, 1997). In female birds, there is a third type of bone, medullary bone, which develops on the endosteal surface in response to initiation of egg laying. Medullary bone is characterized by a high rate of remodeling and serves to provide a labile source of calcium to support eggshell formation (Dacke et al., 1993).

8.2.2 Influencing factors

A variety of factors are known to influence pullet skeletal development, though individual factors are often interrelated and difficult to differentiate. For instance, locomotion by birds within a particular housing system is likely to influence skeletal development (Casey-Trott, 2016; Fleming et al., 2006; Regmi et al., 2015), an example of environmental influence. However, birds of different genetic lines are also known to utilize aspects of the environment (e.g., perches; Faure and Jones, 1982) in different ways, which confounds quantification of either factor. The following subsections seek to provide a general assessment of three broad areas, but it should be understood that effects will likely be interdependent.

8.2.2.1 Environment

The environment is a powerful factor in pullet development, with the nature and magnitude of its effects depending on the types of activity that the pullets can

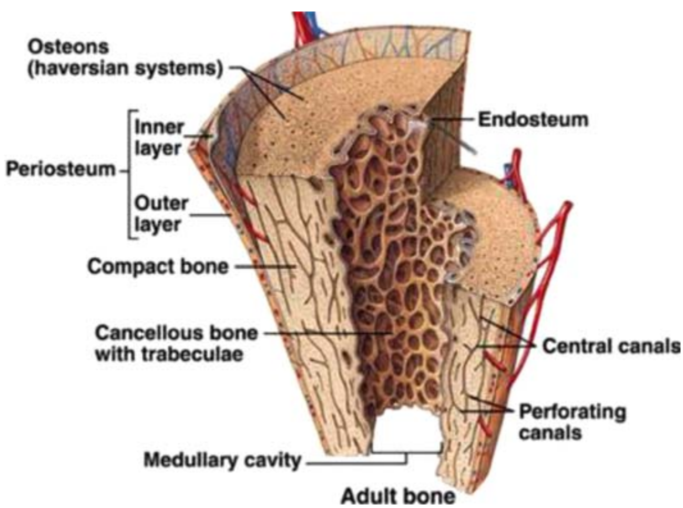

Figure 8.1 Cross section of a long bone showing various layers and bone types.

perform in a particular environment. Activity levels that result in increased bone loading are well known to benefit bone growth (Isaksson et al., 2009), including in pullets (Biewener and Bertram, 1994). Hence, there have been investigations to identify or encourage activities with beneficial effects on bone health. One method of increasing activity is to provide perches, an important resource which hens appear highly motivated to use, particularly at night for roosting (Olsson and Keeling, 2000). In examining the effects of provision of perches on musculoskeletal development in caged pullets, Enneking et al. (2012) identified increased bone mineral content of the tibia, sternum, and humerus with an accompanying increase in leg muscle and total body weight in comparison to pullets without perch access. These benefits did not appear to carry over to the laying phase, however, where the only difference attributable to rearing was an increase in keel bone mineral content at 50 weeks of age (Hester et al., 2013). Hester et al. (2013) concluded that the lack of more systemic changes could be attributed to the relatively low height of the perches. It is possible that the greater force (and consequent loading) required to ascend/descend higher perches could have led to more long-term changes.

Multiple studies have sought to compare different rearing environments that would allow for gross differences in activity, rather than making a direct comparison between a specific aspect of an environment like perches. For instance, Regmi et al. (2015) reared birds in cages until they were 6 weeks of age, after which they remained in cages or were transferred to a multitier aviary. The pullets were then examined for multiple structural and biomechanical properties of the tibia and humeri at various time points. The authors reported a variety of differences in response to rearing conditions in the measurements taken at 16 weeks of age, including greater cortical thickness, density, and overall bone mineralization, as well as stiffer and stronger bones, in the pullets that were aviary reared. Although they did not quantify the types of activity and their frequency, the authors attributed the observed skeletal differences to the variable loading and activity that would be required for the pullets to navigate between the aviary tiers, including wing-flapping and jumping between perches and tiers. For instance, interactions between housing conditions and bone type (i.e., tibia and humerus) for the responses of cross-sectional area and bone rigidity suggested that the bone types were exposed to different types of loading in the two environments (Regmi et al., 2015). Other studies comparing cage and noncage rearing environments have shown similar improvements in bone strength and characteristics (Casey-Trott et al., 2017a; Fleming et al., 2006), with benefits extending to 73 weeks of age (Casey-Trott et al., 2017b).

The positive effects of environment and increased activity on bone development can extend to the late stages of pullet development (i.e., 15–23 weeks of age), although they will have less of an influence on the formation of structural cortical bone as the pullets come into lay and be less beneficial in the long term. The reduced benefit stems from the site of mineralization gradually shifts to the less structurally important medullary bone and away from cortical bone formation. Fleming et al. (2006) compared cage and aviary housing from 15 weeks of age following rearing on deep litter and reported that at 20 weeks of age, mineralizing surfaces, previously found on the outer periosteal surface, were now limited to the medullary bone. No differences were seen between housing types. However, while bone formation was no longer responsive to housing conditions, resorption continued to be affected. Aviary birds had a greater true cortical area and reduced presence of osteoclasts at 25 weeks of age, suggesting resorption continued to respond to housing type (Fleming et al., 2006).

A specific type of behavior relevant to the rearing environment that has recently attracted attention is the development and performance of wing-assisted incline running (for a review of this topic see Dial, 2003; Tobalske and Dial, 2007). Although this activity has yet to be investigated in terms of direct effects on skeletal development in commercial hens, early exposure to variable inclines and surfaces is likely to influence cognitive navigation abilities (LeBlanc, 2016), which in turn will influence how the pullet uses her environment (Widowski and Torrey, Chapter 3).

8.2.2.2 Nutrition

Provision of adequate nutrition during rearing is understood to be critical for bone development in pullets. Assuming she is in lay the entire time after rearing, it is the only age in a commercial hen's life during which she forms structural cortical bone (Whitehead and Fleming, 2000) and thus delivering appropriate nutrition to maximize bone health during this time is essential. Calcium, given its dominant role in bone composition and structural integrity, is the most important mineral. The effectiveness of calcium on bone health is dependent on a variety of factors including the source (Fleming, 2008) and other dietary components that affect calcium homeostasis (Shafey, 1993). The role of other important dietary components, including vitamin K, D, and phosphorous, for bone health during pullet development is reviewed elsewhere (Fleming, 2008; Hatten et al., 2001; Kornegay, 2001). Age is also likely to interact with nutritional factors. For example, increasing calcium has only limited benefits in the final weeks before and immediately after hens come into lay (Leeson et al., 1986). A pullet is also limited in the amount of calcium she can absorb in the short term before metabolic disorders develop (Guo et al., 2008), therefore inclusion of calcium to improve bone health does have an upper physiological limit. Given these variations, within physiological ranges calcium will act in a concentration-dependent manner, with increasing levels being associated with proportional increases in the breaking strength, weight, ash, and mineral content of tibias in pullets (Frost and Roland, 1991) and broiler breeders (Moreki et al., 2011).

In an effort to provide more calcium for bone development, researchers have investigated using calcium of larger particle sizes to provide a steady release of calcium over a longer period of time, e.g., during the night when the eggshell forms. Research on this technique has generally focused on improving eggshell quality in hens approaching end of lay (Guinotte and Nys, 1991; Saunders-Blades et al., 2009; Skřivan et al., 2010; Tunç and Cufadar, 2014), although particle size has also been investigated during the later stages of pullet development. Fleming et al. (1998) found that particulate limestone fed from 15 weeks of age reduced cancellous bone loss and increased accumulation of medullary bones by 25 weeks of age as compared to powdered limestone. A lower number of active osteoclasts at 25 weeks of age (Fleming, 2008) indicated a reduced mobilization of endogenous mineral, which the authors reasoned was driven by greater dietary calcium being available during egg formation. Thus, particle size should also be considered for pullets, mostly during later stages as they come into lay.

8.2.2.3 Genetics

Early investigations of genetic control of bone health in poultry were conducted by Warren (1937) and Hyre (1955), who investigated the heritability of "crooked keels" and the relationship with influencing factors. In more recent work by Bishop et al. (2000) two genetic lines were bred for relatively high and low bone strength while keeping body weight relatively stable. The index that the researchers developed, which incorporated bone strength and related measures, was shown to have a heritability of 0.4, with dramatic differences between the two lines for tibia and humerus strength and keel radiographic density. Fleming et al. (2006), as part of a large study examining variation between these two genetic lines across different housing conditions (cage, aviary) and diets, concluded that genetic control was likely the most important factor in determining bone health. While the factors were additive, the authors suggested that the capacity for improvement through environmental and nutritional interventions will ultimately be limited by genetically controlled factors.

8.3 Keel bone damage

8.3.1 Introduction

The high frequency of fractures seen in the keel bone of hens within commercial systems represents one of the greatest welfare problems facing the industry, as suggested by the UK's Farm Animal Welfare Committee (FAWC, 2010, 2013) and a leading group of poultry researchers (Lay et al., 2011). Beyond the obvious welfare issue of gross skeletal deformities, concern stems from the likely associated pain and suffering indicated by a shorter latency to descend from perches in hens with fractures that was reduced with anti-inflammatory agents and analgesics (Nasr et al., 2012b, 2015). General behavioral changes reported in hens with fractures include more perching (Casey-Trott and Widowski, 2016) and less time standing (Casey-Trott and Widowski, 2016; Nasr et al., 2012a). Production losses have also been theorized to be a concern (Thiruvenkadan et al., 2010), with limited data estimating a reduction in egg production (Nasr et al., 2013; Rufener et al., 2016).

Keel fractures can be defined as breaks in the bone that typically manifest as a callus around the fracture site but may also involve sharp, unnatural deviations or bending (Casey-Trott et al., 2015). Recent assessment by research groups in a variety of countries indicates that levels of keel bone damage are exceptionally high, typically in excess of 50% by the end of lay [Canada (Petrik et al., 2015), Belgium (Heerkens et al., 2013), Holland (Rodenburg et al., 2008), Switzerland (Kappeli et al., 2011), United Kingdom (Tarlton et al., 2013; Toscano et al., 2015; Wilkins et al., 2011)]. In addition, the problem appears to occur in many types of housing systems (Wilkins et al., 2011), including conventional and furnished cages (Petrik et al., 2015) and organic (Bestman and Wagenaar, 2014) systems, and across genetic lines (Candelotto et al., 2017; Kappeli et al., 2011). The problem has also been observed in commercial broiler breeder flocks (Gebhardt-Henrich et al., 2017).

8.3.2 Causes of keel bone fracture

Several factors have been investigated in pursuit of identifying causative mechanisms of fractures and conditions which contribute to variations in susceptibility of individual hens, with a particular focus on nutritional and environmental factors.

8.3.2.1 Calcium demands of egg production

The theory which has attracted the greatest attention as to the source of fracture is that the high demands of calcium required of contemporary commercial hens for egg production (approximately 320 eggs over a 365-day period, i.e., nearly an egg per day) induces resorption (breakdown of the bone matrix and release of contained mineral), leaving bones weak and brittle (Fleming et al., 2004b; Whitehead and Fleming, 2000). While not a cause of fractures by itself, this condition leaves the hen relatively susceptible to fractures from more direct causes such as collisions with housing objects (discussed later). Concerns were first reported by Couch (1955), who coined the term "cage-layer fatigue" for a syndrome that appeared to be associated with broken bones and paralysis due to weakening and eventual collapse of the spinal column. The original condition was believed to be exacerbated by inactivity in the cage environment, although the widespread occurrence of fractures in modern systems (both cage and noncage) suggests that the problem of poor bone health persists even in environments where birds are relatively unrestricted in their movement.

As already discussed, the bones of hens are composed of three primary types—cortical, trabecular, and medullary. Cortical and trabecular bone serve as the main structural components and are continually formed up to the onset of sexual maturity at 18 weeks of age. From this point forward, medullary bone is formed within the bone's interior which provides little structural support, instead serving as a labile storage of mineral for eggshell formation (Whitehead and Fleming, 2000). The approximately three grams of calcium required for each eggshell (Roberts, 2004) is partially provided by the diet (60%−75%) with the remainder coming from endogenous sources, principally bone. With the onset of sexual maturity cortical bone is no longer produced (Hudson et al., 1993) and the process of bone resorption supplements the exogenous (dietary) calcium required to form the eggshell. As the processes of resorption and formation continue throughout the lay cycle ($\sim$50 weeks in modern flocks), hens manifest an increase in total bone mineral but a net loss of mineral in structural (cortical) bone from a peak at sexual maturity (Wilson et al., 1992). It is this loss of structural bone that is thought to be responsible for the gradual weakening and the increased frequency of bone fracture.

Efforts have been made to extend the period of availability and retention of calcium from the diet using different forms of calcium (e.g., larger size such as particulate limestone Lichovnikova, 2007; Rennie et al., 1997) to make eggshell production less reliant on endogenous sources. Efforts have also been directed at increasing the stimulation of bone formation with dietary fluoride (Rennie et al., 1997) and or additives that reduce calcium precipitation (e.g., phosphopeptides Jiang and Mine, 2001) to increase calcium absorption. Nonetheless, it is generally believed that a threshold has been reached where the hen's capacity for absorption cannot be increased (Newman and Leeson, 1997) and high dietary calcium levels may even cause kidney lesions (Guo et al., 2008; Whitehead, 1996). Thus, supplying more calcium to the hen via the diet may not a feasible solution to improve bone health.

Although the concept of high egg production draining bone mineral and weakening the hen's skeletal structure offers a convincing mechanism to explain the increase in keel fractures, variation in the appearance of fractures over the course of the laying cycle suggests involvement of other factors. For instance, the increase in the number of fractures seen in commercial settings is nonlinear, with a dramatic rise between 25 and 35 weeks of age (Tarlton et al., 2013; Toscano et al., 2015) and then a decrease or plateau beyond ~37 weeks of age (Heerkens et al., 2013; Petrik et al., 2015; Stratmann et al., 2015b; Toscano et al., 2015). The decrease in fractures occurs despite continuation of relatively high egg production rates, i.e., greater than 0.85 eggs/day, and appears to be associated with changes of a nonbehavioral nature (e.g., skeletal integrity) (Toscano et al., 2014). Toscano et al. (2014) suggested that changes in the skeletal system, particularly final ossification and hardening of the bone structure, were responsible for the age-related decrease in fractures. Rath et al. (2000) found evidence to support this possibility where, despite markers of tibia growth (weight, length, diaphyseal diameter) peaking at 25 weeks of age, changes in the allometric, biochemical, and biomechanical nature of tibias continued, peaking at 35 weeks of age.

Another issue causing ambiguity when evaluating the relationships between egg production and keel damage is that the majority of studies on bone mineral loss over time in laying hens have focused on the long bones as proxies for the keel. The substitution is largely due to the unusual function and shape of the keel bone, which makes biomechanical assessments difficult. However, long bones may not respond in a uniform (Toscano et al., 2013) or even parallel manner (Toscano et al., 2015) to the keel bone, so long bone comparisons may not be relevant. Additionally, the majority of work investigating links between egg production and keel damage was performed on hens maintained in conventional cages and may not be relevant to noncage systems that allow for much greater movement (e.g., aviaries and furnished cages). In this scenario, behavioral differences between hens in these systems could have profound effects, which need to be considered when interpreting results from different studies. Thus, while the effect of egg production is likely a major influence on keel damage susceptibility, additional investigation is required to explore the concept and the role that other factors play in the occurrence and severity of keel fractures using methods that examine the keel directly.

8.3.2.2 Physical environment—A direct cause of fractures via collisions

A second factor, which appears to have a major influence on the frequency of keel bone fracture, is the hen's physical environment. In comparison to hens kept in a caged system, those maintained in a noncage housing system have a greater prevalence of fractures, and this problem increases if perches are provided (Sandilands et al., 2009). Wilkins et al. (2011) suggested that the variation in fractures observed between systems was likely due to perches (and other system furnishings) in some systems, resulting in more high energy collisions, a view supported by the increased fracture occurrence and severity seen in systems with greater environmental complexity (i.e., more and higher items available for perching). Observations have detailed collisions specifically within an aviary environment (Stratmann et al., 2015a), where hens had collisions as they sought positions at higher elevations, particularly during the dusk/dark transition. During this transition period, sitting hens occasionally get pushed from their positions by other hens or fail to navigate correctly, particularly where local density is very high. Paradoxically, birds in noncage systems have superior bone strength (Jendral et al., 2008; Tauson and Abrahamsson, 1994) compared to caged birds, which perches likely contribute to by allowing greater movement between vertical sections. This indicates the difficulty in identifying an appropriate balance between providing an important resource that birds are motivated to use and that leads to improved bone strength (i.e., perches) while limiting injury (Sandilands et al., 2009).

8.3.2.3 Physical environment—Indirect cause of fractures

Beyond the physical environment as a direct source of fractures, the physical environment also likely plays an indirect role, particularly during the rearing period before the onset of sexual maturity when the keel has not ossified and fractures are exceedingly rare. The rearing environment can have effects that last throughout the hen's life, likely via several mechanisms. These include variations in development of biological (e.g., musculoskeletal) factors and cognitive abilities, for example, related to the capacity to navigate and judge distances. Thus, a rearing environment that does not allow for appropriate development should be considered as contributing to fracture development.

In terms of biological factors, given that commercial hens cannot create more of the critical structural bone following the onset of sexual maturity because of their near-continuous egg production (Hudson et al., 1993), it is important to enhance the already described process of structural bone development during the rearing period (Fleming et al., 2004a; Whitehead and Fleming, 2000). In general, rearing hens in environments that allow for physical activity has a positive effect on (nonkeel) bone strength (Fleming et al., 2006; Newman and Leeson, 1997; Regmi et al., 2015; Whitehead, 1996) and mass (Knowles et al., 1993), although conflicting results have been reported (Gregory et al., 1991). In terms of specific biological changes and rearing environments, birds provided with perches (within caged systems) during the rearing phase manifested greater bone mineral density and mass of specific muscles during the egg laying phase (Hester et al., 2013). Surprisingly, Hester et al. (2013) found no effect of perch presence during rearing on frequency of keel fractures. A possible explanation for this lack of benefit may be that the magnitude of energetic forces the keel is required to withstand in a cage system are relatively minor in comparison to aviary systems where hens typically descend from heights greater than 3 m. In contrast, Casey-Trott (2016) reported that aviary reared pullets did have fewer keel fractures than conventionally reared pullets throughout the laying period, with correlated changes in skeletal characteristics such as greater bone cross-sectional area.

An appropriate rearing environment is also critical to ensure adequate development of cognitive mechanisms necessary throughout the hen’s life (Tzschentke and Plagemann, 2007). This is particularly important for a hen in an aviary environment, where she must develop the abilities necessary for to navigate multiple levels, including perches 0.5 to 2 m above ground and tiers which can be upward of 3 m high. As an example of how rearing can influence cognitive development, Gunnarsson et al. (2000) compared young pullets with and without access to perches during the first 8 weeks of rearing. Those without early perch access had a shorter latency to access a food reward on a raised platform of 80 or 160 cm in comparison to those that had continuous access to a perch throughout rearing. Interestingly, there was no difference when birds were required to ascend only 40 cm. The authors reasoned that because the differential physical ability the pullets needed to reach the 40 and 80 cm platforms was negligible, this shorter latency was due to the enhancement of cognitive abilities in the pullets provided with early exposure to perches during rearing. Similarly, birds without access to perches during rearing have been shown to lay a greater proportion of eggs on the floor rather than in raised nest boxes, which the authors reasoned was due to difficulty in accessing the elevated platform in front of the nest boxes (Appleby et al., 1983, 1988).

8.3.3 Solutions

Reducing the frequency and severity of keel bone damage is unlikely to be accomplished by a single change. Instead, there are multiple approaches that producers/nations should adopt as the most appropriate for their own conditions. Harlander-Matauschek et al. (2015) provide an overview of nine specific areas for research to aid this ongoing effort, of which the most critical are reviewed within this section.

8.3.3.1 Housing and management

As suggested above fractures are believed to be related to collisions, as more complex housing systems with a greater number of perchable objects at greater heights correlate with the number and severity of fractures (Wilkins et al., 2011). However, collisions can only offer a partial explanation, as a considerable number of fractures also occur within caged (conventional and furnished) systems, albeit with less frequency and severity (Hester and Enneking, 2014; Petrik et al., 2014; Wilkins et al., 2011), confirming the influential role of housing. Hens in furnished cages have collisions with an associated energy of impact within the range of impact energies seen in aviary housing (Baker et al., 2016; Mackie et al., 2016), so the nature of collisions within different housing systems will require further investigation. Within noncage systems, the actual angle and height between adjacent perches has been shown to have a dramatic effect on the ability of hens to achieve a safe landing when moving between locations (Moinard et al., 2004; Scott et al., 1997). Current recommendations suggest the angle between vertically arranged perches should not exceed 45 degrees (Lambe et al., 1997; Scholz et al., 2014; Scott et al., 1997) and that horizontal perches should be spaced less than 50 cm apart (Scholz et al., 2014) or 75 cm (Scholz et al., 2014; Scott and Parker, 1994; Scott et al., 1999; Taylor et al., 2003). Other factors such as the perch material and shape (Pickel et al., 2011; Scholz et al., 2010, 2014; Stratmann et al., 2015b; Tauson and Abrahamsson, 1996), should be considered for improving housing design. Struelens and Tuyttens (2009) provide a review of the influence of perches on hen health and behavior, including keel bone damage.

In addition to perches, other housing factors shown to influence the frequency and severity of keel bone damage include the floor material (Heerkens et al., 2014), distance between aviary sections (Heerkens et al., 2014), and inclusion of walking paths (i.e., ramps) between aviary tiers (Heerkens et al., 2016; Stratmann et al., 2015a). The rearing environment, as already discussed, likely plays a critical role in providing chicks sufficient skeletal development for later locomotion as adults (Heikkilä et al., 2006; Whitehead and Fleming, 2000) and possibly improved cognitive abilities for moving between perches (Gunnarsson et al., 2000; LeBlanc, 2016). In designing laying environments, it is important to consider the morphological limitations of the hen's musculoskeletal system when navigating her environment (Harlander-Matauschek et al., 2015). In this sense, it would be unreasonable to expect a hen to use a steeply positioned ramp if she had not developed the musculature and bone strength required to ascend it.

8.3.3.2 Nutrition

Efforts to improve bone strength have largely dealt with improving calcium delivery for egg production or slowing the process of demineralization. One nutritional strategy to improve bone health is use of omega-3 fatty acids, which can modulate bone metabolism and modeling and the processes which drive bone demineralization (Baird et al., 2008; Liu et al., 2003; Watkins et al., 2003). Intervention with omega-3 enhanced diets has been shown to result in reduced fracture incidence (Tarlton et al., 2013; Toscano et al., 2015). Beyond benefits to the hen, omega-3s, which are absorbed into the egg yolk, are also known to benefit human health (Calder, 2006, 2009), thus omega-3 supplementation can provide benefits to the human consumer as well. There is also evidence from various animal studies, however, that omega-3s can have detrimental effects on health, possibly through interactions with immune function (Anderson and Fritsche, 2002) or production of damaging free radicals (Aruoma, 1998). The detrimental effects also appear relevant for laying hens (Toscano et al., 2012, 2015). If omega-3s are to provide a solution for keel bone damage, diets will need to be optimized not only in consideration of bone integrity, but of omega-3 egg content and overall hen health.

Larger calcium particles take longer to break down and thus maintain elevated dietary calcium throughout a 24-hour period. Provision of limestone particulate, oystershell, or other forms of calcium with a relatively large particle size have been advocated as a solution for end-of-lay hens to maintain eggshell quality and extend the lay period up to 100 weeks of age (Pottgüter, 2016; Thiele et al., 2015). Eggshell formation occurs in the evening when the hen is sleeping and is associated with a ninefold increase in resorption (Van De Velde et al., 1985) to provide greater calcium to supplement dietary sources as needed. Larger dietary calcium particles can, thus, increase the amount of calcium available during this critical night time period. Although all published work on this strategy has focused on eggshell quality, the reduced need for endogenous calcium, e.g., from bone, would likely extend to the keel as well and, thus, aid in maintaining skeletal integrity. In other words, as greater amounts of calcium would be available in the blood from the diet, less would be required from the bone. Beyond the form of calcium, feeding the daily requirement of calcium towards the end of the day and/or the last feeding has also been suggested as a strategy to increase calcium concentrations at night and reduce the need for bone resorption (Thiele et al., 2015).

8.3.3.3 Genetics

Genetics has been proven to be a valuable tool to decrease keel deformities and future work will require a renewed focus on current problems. Bone health has been successfully manipulated over five generations, leading to an understanding of the genetic loci controlling bone quality (Dunn et al., 2007) and also providing benefits to overall skeletal quality (Bishop et al., 2000; Sparke et al., 2002), including reduced broken keels (Bishop et al., 2000). While these latter studies were originally performed in noncommercial, group-housed birds, the benefit of reduced keel damage was replicated in an aviary environment (Stratmann et al., 2016) demonstrating the far-reaching effects of genetic manipulation. A comparison of four distinct purebred genetic lines and one crossbred lines (including three commercial lines) identified extensive variation in susceptibility to keel bone damage using a study protocol that minimized environmental variation and behavioral differences at the time of fracture (Candelotto et al., 2017). Collectively, these studies demonstrate that there is genetic potential within commercial lines to not only lay a high number of eggs but maintain good skeletal quality. However, the method of assessment of bone quality relies on killing the birds, which precludes subsequent breeding. Therefore, a key step to reducing keel bone damage by genetics is the development of techniques to measure keel bone quality reliably without killing the hen, a challenge and factor in why bone strength has not been included as a major selection trait.

Recent efforts to overcome this problem have developed approaches for identifying phenotypic measurements or genetic/metabolic markers that explain variance in keel bone quality. Novel methods (e.g., radiography, ultrasound) which have been applied to the keel bone may also be a solution (Fleming et al., 2004a; Richards et al., 2011). Alternatively, the promise of modern selection methods (e.g., whole genome selection, Fulton, 2012; Jensen, 2018) may allow terminal phenotypes to be utilized. Ultimately, these advanced methods will only be effective if practical, relatively high throughput methods can be used to develop phenotypes for relevant housing conditions. Additionally, the influence of egg production on bone properties may have a genetic basis (Fleming et al., 1998; Whitehead and Fleming, 2000) and efforts to select for superior genetic traits that confer resistance to keel bone damage will need to consider the likely but as yet undefined role that egg production has on bone health.

8.4 Musculoskeletal injury during depopulation

8.4.1 Causes of injury

Gregory and Wilkins (1989) reported that an average of 24% of hens (ranging from 13% to 41% of farms surveyed) had a broken bone immediately following commercial depopulation from conventional cages, which they attributed to the removal process. Similar levels of damage have been reported in aviaries (10.1%; Gregory et al., 1990). The multiple tiers of aviaries, while undoubtedly providing benefits to hens in terms of dustbathing, perching, and vertical motion (Lay et al., 2011; Rodenburg et al., 2008; Weeks and Nicol, 2006), also introduce their own problems, of which hen removal at the end of the laying cycle is one. Given the multiple, vertical tiers that the hens are distributed across within many open aviary systems, catching the hens and carrying them to the transport crate will often be much more difficult than the process in caged systems. Thus, while there are many similarities between removal processes for cage and noncage systems, the latter is likely to involve more severe injuries and fear responses in the hens as well as physical challenges and hazards to the human catcher.

Bones commonly found to be broken during removal from cages include those of the hips and legs: humerus, ischium, and pubis (Gregory and Wilkins, 1989; Gregory et al., 1990). These injuries are likely to occur as the hens are forcefully pulled from the cage (or resting/perching position in the aviary) and carried to the transport crate. Additionally, hens are routinely held by a single leg while being carried, resulting in twisting that can easily cause bone fractures or lesions

(Langkabel et al., 2015). During this process, hens may be passed from a person performing the initial catching to a second person responsible for carrying, and then possibly a third person who actually loads the hens into a transport crate. Each time hens are passed between handlers it creates an additional opportunity for injury, as the position of the hens is often rotated to accommodate the change in grasp.

In support of the notion that improved handling during this stage of removal can lead to reduced injury, removal of birds with two hands versus one reduced injury from 14% to 5% (Gregory et al., 1993). Similarly, Gregory and Wilkins (1989) found that when hens were handled one at a time and brought to the transport crate, the rate of injury fell from 24% to 14%. Other bones which experience high rates of damage during depopulation are the keel (Gregory and Wilkins, 1989; Gregory et al., 1990) and wings (Gregory et al., 1990; Kristensen et al., 2001). This likely results from hens colliding with the sides of their home cage during removal or when placed into the transport crate (Knowles and Wilkins, 1998; Van Niekerk and Reuvekamp, 1994).

8.4.2 Solutions

A variety of means have been pursued to reduce injury in laying hens (and broilers) during depopulation, with moderate success. These include legislation and better training of poultry handlers (Kettlewell and Mitchell, 1994; Pilecco et al., 2013), as well as technical improvements in how birds are collected and removed (Kristensen et al., 2001; Lacy and Czarick, 1998). In terms of technical improvements, the efforts have largely focused on reducing handling time of the hens by humans. For example, Kristensen et al. (2001) evaluated a modular system that allowed the crates to be wheeled directly to the source conventional cage where the hens were loaded and then brought to the conveyance truck. In this manner, hens need only be handled twice—at initial loading and then removal at the slaughter plant. Use of the modular system reduced handling time (65.4−4.5 seconds, SED 3.6 seconds) and was overwhelmingly preferred by staff, although no differences were seen in the frequency of damage to hens. These efforts need to be further pursued, particularly given the increased use of aviaries and anticipated elevated rates of injury.

8.5 Conclusions and implications

The laying hen industry is undergoing dramatic changes in terms of care and housing in response to consumer concern for animal welfare while at the same time advances in nutrition and genetics have resulted in a highly efficient hen capable of producing over 320 eggs per laying cycle up to 100 weeks of age. With these changes, hens appear to have increased susceptibility to skeletal problems during the laying period manifesting as damage to the keel bone throughout the egg production cycle and more general damage during the depopulation process.

An understanding of the causes of skeletal problems must first consider the unique processes that pullets undergo during rearing in the period leading up to sexual maturity. As the pullet grows and her bones undergo elongation and widening, the bone will gradually develop an outer, compact cortical and an inner cancellous bone. After reaching sexual maturity marked by the onset of lay, the bone will largely retain the same exterior dimensions while continuing to change and mature in terms of internal structure and linkages.

Although continuing changes to bones during a hen's development impart some measure of increased strength, the growth of cortical bone will cease as long as the hen remains in lay, i.e., the remainder of her life. Hence, rearing is a critical period in the hen's life to ensure development of the necessary bone quality and strength for the range of movement required in the laying period. During rearing, many factors and their interaction will influence the final skeletal composition of the mature bird, which can roughly be broken down to genetics, nutrition, and environment. While the three factors are likely additive and dependent on the others, genetic potential will ultimately be the limiting factor in development. With the current/recent shift in hen housing away from conventional cage systems to alternative systems, there is a need for research in all areas to investigate the role of these factors within different systems. For instance, bone loading will enhance strength of that bone but the effect is not systemic, and thus, it is critical to match housing during rearing with the appropriate laying environment that provides matching development. Similarly, it will be equally important to match the required calcium and essential mineral needs of the hens to the demands of the housing system.

Laying hens have two major types of skeletal problems and both appear during lay, with the principal cause believed to be high and/or extended periods of egg production resulting in bones of poor quality. One type, keel bone damage, is broken into the two subcategories of bending and fractures, where the former is believed to result from sustained, relatively minor pressure over time, e.g., during perching. The other subcategory of keel damage is fractures which result from sudden and brief forces on the keel, such as hens colliding with pen structures, resulting in fractured bone, or possibly from internal forces within the bird such as breast muscle pulling on the keel and exceeding the bone's ability to resist damage. Bending of the keel is a result of bone remodeling so is unlikely to cause the bird pain, although it weakens the keel making fracture more likely. In contrast, fractures are understood to be associated with pain and likely lead to decreased productivity, though work is required to verify these associations. Nonetheless, the gross deformities seen in 25%–90% of hens in commercial flocks (depending on age, system, and other factors) have led several government bodies, nongovernmental organizations, and other institutions to declare keel fractures as one of the leading animal welfare problems in the laying hen industry.

Although sustained and high egg production is believed to be the principal cause for the underlying problem of weakened bone, the rate of new fractures with increasing age does not appear to increase as would be expected given that birds remain in lay and are not forming structural bone. Rather, both the plateauing of fractures observed on-farm and work employing an ex vivo model suggest that factors such as changes in underlying bone properties serve to mitigate the detrimental effects of egg production. Alterations in behavior, including decreased activity and improved navigation ability in older hens, will also have an influence. Thus, further research is needed to understand the causes of keel bone damage and the role of production.

As the precise causes of keel bone damage remain unclear, solutions to resolve it remains tenuous, although generally fall into three categories: housing and management, improved nutrition, and effective breeding. In terms of housing, various factors, including positioning, shape, and material of perches, have all been shown to relate to navigation success of hens within noncage systems. Distance between aviaries positioned in rows, the tier surface material, and the presence of walking paths between tiers have also been shown to relate to the presence of keel damage. Nutritional solutions have focused on physiological factors to reduce bone resorption and increase bone formation, though timing of calcium delivery should also be investigated. Lastly, breeding is likely to hold enormous potential and dramatic achievements have been made, though a challenge until fairly recently has been limited techniques to assess traits of interest in live birds. With the advent of improved assessment methods such as radiography and a greater understanding of causative factors, development of phenotypes should advance rapidly.

A second type of skeletal problem in laying hens is the injury (e.g., to bone and soft tissue) which results from depopulation. As with keel damage, this problem has its roots in poor bone health, and it is exacerbated by certain types of housing where removal of hens is difficult. The global trend away from caged systems to alternative housing such as aviaries is likely to worsen the problem. Damage will be widespread to multiple bone (and tissue) types as the hens are pulled from their cages or resting position on perches, carried, and then placed in transport crates. Solutions to decrease this type of injury will likely include improved training of handlers and technical improvements in the collection of hens, including the use of methods that reduce handling time by the handlers.

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Feather pecking and cannibalism: Can we really stop beak trimming?

9

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9.1 Introduction

Gentle (GFP) and severe feather pecking (SFP) are forms of inter-bird pecking which have different appearances, causes, and patterns of gene expression (Rodenburg et al., 2013) and very different consequences for bird welfare. The gentle pecking of feather tips is a highly prevalent behavior observed during both the rearing and laying periods (Gilani et al., 2013; Lambton et al., 2010; Nicol et al., 2013). It can be preferentially directed toward unfamiliar chicks as a form of social exploration (Riedstra and Groothuis, 2002) or it can take a more stereotyped repetitive and invariant form. In either case the resultant plumage damage is often minor, so GFP is a concern mostly because of its (still unclear) relations with more serious forms of pecking. In younger birds correlations between exploratory GFP and SFP have been noted (Newberry et al., 2007), and a few studies have suggested that GFP may precede or develop into SFP in older birds. However, the majority of studies, especially those on commercial flocks, have shown no clear causal or temporal link between early GFP and adult SFP (Hartcher et al., 2015a; Rodenburg et al., 2013) but further work is clearly needed to clarify whether relationships between different forms of FP occur in some circumstances.

SFP involves pecking, pulling, or removing feathers from a recipient bird. It has a far more serious effect on bird welfare and flock productivity than GFP. It is painful for the recipient, and victims often react adversely by squawking and moving away. SFP results in substantial plumage loss (Drake et al., 2010; Lambton et al., 2010), skin damage, increased susceptibility to infection (Green et al., 2000), loss of production, increased demand for food, and increased mortality (Nicol et al., 2013; Rodenburg et al., 2013). SFP can be performed repetitively, although it is not associated with a heightened tendency to continue ongoing behavior rather than switching between behaviors. Thus SFP does not show the characteristic of general perseveration associated with many stereotypies (Kjaer et al., 2015).

SFP can be observed during the rearing period (Gilani et al., 2013; Lambton et al., 2010) although it does not generally occur at the high prevalence levels seen for GFP. The likelihood of SFP increases greatly as hens reach sexual maturity and begin to produce eggs (Nicol et al., 2013). Since SFP is strongly related to feeding and foraging variables, it may be triggered at the start of the productive phase

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because of greatly increased nutritional demands. Evidence for the involvement of nutritional and dietary factors in the onset of SFP comes from experimental, epidemiological, and genetic studies. The risk of SFP is greatly increased by feeding pelleted diets that are eaten quickly (Aerni et al., 2000; El-Lethey et al., 2000; Lambton et al., 2010; Lindberg and Nicol, 1994; Savory et al., 1999) and by the provision of limited foraging opportunities (Savory et al., 1999). Studies of gene expression in birds with a high tendency to peck reveal associations with genes concerned with nutrient absorption and the regulation of glucose homeostasis (Brunberg et al., 2011). Inadequate amino acid and protein levels are linked with SFP, as are low fiber levels (Elwinger et al., 2008; Hetland et al., 2003; Kriegseis et al., 2012; Qaisrani et al., 2013; Rodenburg et al., 2013; Steenfeldt et al., 2007; Van Krimpen et al., 2009). In addition, SFP is often accompanied by feather eating, and this may be one way that birds can obtain additional fiber in their diets (Harlander-Matauschek and Häusler, 2009).

Vent pecking (VP) is directed to the tissue surrounding the cloaca of another bird, while cannibalistic behavior is the term used for pecks directed to other areas of skin and tissue (Savory, 1995). VP, cannibalism, and SFP are all forms of injurious pecking (IP) and they share many risk factors, although spontaneous outbreaks of tissue pecking can sometimes occur in the absence of SFP (Lambton et al., 2015; Pötzsch et al., 2001). Overall, relatively few studies have attempted to disentangle specific risk factors for VP and cannibalism separately from risk factors for SFP. The best information available suggests that low protein and low fiber diets have a strong influence on the occurrence of pecking-related mortality (Ambrosen and Petersen, 1997; Hartini et al., 2002), while two studies have identified specific management practices associated with VP. These include illumination within the nest boxes (this practice may increase the attractiveness of the cloacal region as a pecking target), the use of bell drinkers, early onset of lay, and a higher number of diet changes during the laying period (Pötzsch et al., 2001), as well as the provision of pelleted feed and certain configurations of perch provision (Lambton et al., 2015).

The exact mechanisms which lead to the development of GFP, SFP, VP, and cannibalistic pecking in laying strain birds are still not fully understood. The risk factors highlighted above act in concert with other genetic and environmental influences to create a highly complex system. Careful and continuous attention to detail is therefore required to prevent outbreaks of FP and occurrence of cannibalism, and this can be both difficult and time-consuming for many farmers. It is perhaps not surprising that alternative damage-limitation strategies have been developed, most notably the practice of beak trimming.

9.2 Beak trimming—Science and policy

Beak trimming, the removal of the sharp upper and lower mandible tips of the beak, is a widespread management practice designed to reduce the degree of damage inflicted if one bird pecks at the feathers or skin of another. Beak trimming can be conducted on the rearing farm, usually when birds are between 5 and 10 days of age, using a hot-blade (HB) technique where a heated guillotine blade (approximately 700°C) cuts and cauterizes the beak tissue. This procedure is also occasionally conducted on adult laying hens as an emergency measure to control an outbreak of cannibalism. A more recent development enables beak trimming to be conducted at the hatcheries using an infrared (IR) procedure. Chicks are restrained by their heads, while calibrated machinery is used to expose a specified area of beak tissue to IR energy. The exposed outer corneum remains intact but the treated beak tip is shed some days after treatment, and regrowth is inhibited due to the extensive penetration of heat to the germ layers.

There is clear evidence that beak trimming can reduce bird mortality in both cage (Guesdon et al., 2006) and noncage systems (Weeks et al., 2016). A meta-analysis of mortality data from 801 beak-trimmed and 228 intact-beak flocks housed between 2006 and 2012 showed significantly (but not dramatically) lower mortality in beak-trimmed versus intact flocks at 40 weeks (2.5% vs 3.2%) and at 70 weeks (7.2% vs 8.3%) (Weeks et al., 2016). This model accounted for factors such as bird age, breed, flock size, and housing system and is the best estimate to date of the effectiveness of beak trimming as a management practice. Beak trimming is also associated with improved plumage condition in adult birds (Sepeur et al., 2015), a finding confirmed both in birds that were IR trimmed as chicks (Lambton et al., 2010, 2013) and birds that were IR trimmed as chicks with an additional "light" HB trim at 11 weeks (Hartcher et al., 2015a). Beak-trimmed pullets also perform less SFP but more GFP than intact birds (Gilani et al., 2013; Hartcher et al., 2015a).

In those European countries where beak trimming is permitted, it is a tightly regulated practice. For example, in the United Kingdom, despite a 2006 Animal Welfare Act that prohibits procedures that involve interference with the sensitive tissues of bone structure of protected animals such as chickens, the practice of beak trimming has continued under various amendments. One amendment that applies in England (the Mutilations (Permitted Procedures) (England) Regulations 2010) allows beak trimming, provided that no more than one-third of the upper or one-third of the upper and lower beak is removed, that trimming is only performed to prevent feather pecking or cannibalism, that it is only carried out using infrared technology, and that it is only performed on birds which are less than 10 days of age.

Despite the benefits of beak trimming and the strict regulation imposed, the practice of beak trimming remains highly controversial. The beak is a complex, innervated organ used in a wide range of behaviors and there are at least three areas of concern.

First, HB trimming results in reductions in growth rate and substantial changes in bird behavior including reduced feed intake, time spent pecking, pecking force and activity (reviewed in Janczak and Riber, 2015). HB trimming also increases adrenocorticotropic hormone levels in the blood and leads to pronounced alterations in indicators of immune function for at least a week after trimming (Xie et al., 2013). These responses to HB trimming can be partially mitigated by the administration of known or putative analgesics (Janczak and Riber, 2015) or by allowing birds themselves to select feed that contains an analgesic (Freire et al., 2008). Analgesic drugs cannot be used outside the laboratory context to manage bird pain in commercial settings but these laboratory procedures provide important support for the inference that the changes seen in response to HB trimming are indicative of pain. The longer term effects of HB trimming depend on bird age and the amount of beak tissue removed. No signs of chronic pain are observed if HB trimming is conducted on very young birds and where only a small portion of beak tissue is removed (Freire et al., 2011). But if a large portion of the beak is removed nerve swellings (neuromas) can form and these may continue to send pain signals to the brain even in adult birds (Janczak and Riber, 2015). IR trimming is thought to cause less pain but this conclusion is tentative (Dennis et al., 2009; Nicol et al., 2013). Birds that have been IR trimmed still show behavioral changes in comparison with untrimmed controls, particularly reduced feed intake and activity in the weeks after the procedure (reviewed in Janczak and Riber, 2015).

Second, the beak is used to perform select, functional behaviors. The effectiveness of preening, for example, is compromised by beak trimming. Birds with intact beaks are better able to remove ecto parasites (northern fowl mites and chicken body lice) than birds that have been HB trimmed as chicks (Chen et al., 2011; Mullens et al., 2010; Vezzoli et al., 2015). Even in birds subjected to relatively mild procedures conducted at 1 day of age and with just the tip of the beak removed, significant changes in navigational ability and functional activity are detected due to damage to mechanorecptors and magnetoreceptors in the beak (Freire et al., 2011).

Third, the practice of modifying animals rather than improving their housing environments is one that many people find disquieting. The very word that is used in many countries to describe the practice—mutilation—is emotive. Rollin has explored the basis for people's unease about modifying animals, whether physically or by genetic engineering and argued that it is not solely dependent on whether the procedure causes pain or interferes with functional activities. Even if (hypothetically) beak trimming raised no substantial ethical concerns related to the welfare of the animals, positions based on human moral character and esthetic ideals associated with providing good animal husbandry might still be used to argue that housing systems should be improved (Rollin, 2015).

Practically, it should be noted that beak trimming involves additional handling of chicks and additional costs. The cost of conducting the IR beak trimming procedure has been estimated at GBP 0.03−0.035 per chick (BEIC, personal communication). The public also has a negative view of beak trimming. In focus group discussions with Flemish citizens, beak trimming was raised as a procedure likely to lower welfare (Vanhonacker et al., 2010). A study of over 900 US consumers found that a majority regarded beak trimming as a practice that would somewhat or definitely worsen laying hen welfare (Heng et al., 2013). Similarly, half of US veterinary faculty who felt they had sufficient information to form an opinion considered beak trimming a procedure that warranted concern (Heleski et al., 2006), while 60% of a broader US population sample considered beak trimming to be an unacceptable way of preventing injury to other birds (cited in Thompson et al., 2011).

The ethical and societal concerns that arise from the beak trimming procedure have led some countries to impose legal bans (Sweden, Norway, and Finland) or to schedule these for the near future (The Netherlands from 2017). Other countries such as Denmark (since 2014) and Germany (from 2017) have instigated voluntary agreements with the poultry industry to phase out beak trimming. Austria engaged in a process whereby farmers who wished to continue to beak trim paid a penalty that was redistributed to farmers keeping intact-beak flocks, and by 2005 fewer than 5% of flocks were beak-trimmed. In contrast, the UK Beak Trimming Action Group (BTAG) considered that the risks of keeping intact-beak flocks were too high for a ban to be implemented in 2016 (BTAG, 2015) and this advice was accepted by the relevant government Minister (Eustice, 2015, written parliamentary answer). His verdict was, however, accompanied by a mandate requiring a national Laying Hen Welfare Forum to monitor progress in implementing strategies to reduce pecking in the national flock and to report to Ministers on a biennial basis. It is therefore relevant to next consider the potential strategies that could be implemented to reduce FP and potentially allow birds to be kept with intact beaks.

9.3 Genetic approaches

A seemingly obvious solution might be to breed laying hens that have a reduced or negligible tendency for feather pecking, as differences between commercial strains in pecking behavior or plumage condition indicative of pecking behavior have long been noted (e.g., Bright, 2007; de Haas et al., 2014b; Klein et al., 2000; Leenstra et al., 2012; Uitdehaag et al., 2008). However, because strains "evolve" each year due to the ongoing strategies of breeding companies, these are not fixed characteristics that can be relied upon. A strain with a low tendency for FP in 2005 may have different behavioral tendencies by 2015. Nonetheless, experimental studies with selected lines show clear genetic components to FP behavior (or to proxy measures of plumage condition) with moderate heritability estimates reported in many studies (Brinker et al., 2014; Kjaer and Sørensen, 1997; Rodenburg et al., 2003; Sun et al., 2014).

A practical demonstration of the feasibility of selecting for or against FP comes from long-standing studies originally instigated in Denmark (Kjaer and Sørensen, 1997). Individual birds showing the highest and lowest bouts of FP have been selected over many generations. The lines have continued to diverge but it has unfortunately proved easier to produce birds with very high or even extreme levels of FP (HFP lines) than to reduce FP to consistently low levels (LFP lines) (Labouriau et al., 2009). In addition, application to the commercial situation has been limited by the existence of inconvenient correlations between FP and useful production traits. It appears that FP may have been inadvertently selected for alongside traits for early onset of egg laying and the ability to use calcium to produce good quality egg shells (Buitenhuis and Kjaer, 2008; Su et al., 2006; Väisänen et al., 2005). This means it may prove more difficult than hoped for breeding companies to develop strains with phenotypes that are both highly productive and unlikely to exhibit FP. Another difficulty in seeking a solution based on genetics comes from the time-consuming nature of phenotyping. It is a lengthy process to wait for outbreaks of FP to occur in adult birds and then analyze the genetic basis of this behavior. An alternative approach discussed next is to search for reliable early markers or predictors of adult FP behavior.

9.3.1 Relationship between FP with other traits and behaviors

Prospective studies have a key role in establishing the nature of relationships between early traits and the onset of FP. By following birds over time it can be established whether a trait such as fearfulness is a predictor of later FP rather than a consequence of preexisting FP. However, prospective studies have produced mixed results. Some have reported poor correlations between relatively easily measured traits (such as fearfulness and exploratory tendency) and later FP behavior or plumage condition (Albentosa et al., 2003; Hartcher et al., 2015b), whereas others have described significant relationships (de Haas et al., 2014a,b). If strong relationships between chick behavior and later adult FP could be more widely confirmed in commercial strains, then early screening programs could be developed. Currently, however, predictive correlations between chick and adult behavior are either too weak or too uncertain to support such investment.

Although prospective studies can help in distinguishing cause and effect relationships, they are also time-consuming to conduct. This may explain why there has been a surge in research aimed at identifying general characteristics that are temporally associated with FP, with the hope of elucidating mechanisms that could provide future targets for selection. In interpreting such studies a distinction must be made between the (rather few) studies on commercially available strains and the growing number of studies conducted on experimentally selected lines. Brunberg et al. (2011) caution that studies on experimentally selected lines can be misleading as these lines may accidentally accumulate genetic variation in traits that are only indirectly, or not at all, related to FP. This caveat must be borne in mind when considering the wealth of data now available on the divergently selected HFP and LFP lines mentioned earlier. Studies have revealed that HFP birds show greater stress responses to physical restraint (Kjaer and Guemene, 2009; Kjaer and Jorgensen, 2011), more aggression (Bennewitz et al., 2014; Grams et al., 2015), fearfulness (Rodenburg et al., 2010b); locomotor activity (de Haas et al., 2010; Kjaer et al., 2015; Kjaer, 2009), foraging behavior (de Haas et al., 2010), altered patterns of serotonin release and dopamine receptor type (Flisikowski et al., 2009; Kops et al., 2014), and improved egg weight, shell thickness and feed efficiency (Su et al., 2006) compared with LFP birds. The HFP birds are also more likely to eat feathers that have been removed than are LFP birds (Bögelein et al., 2015; Meyer et al., 2013), and are less likely to persevere in certain operant tasks (Kjaer et al., 2015). The associations that are detected may vary depending on whether genetic or phenotypic correlations are considered. For example, Grams et al. (2015) reported no phenotypic correlation between juvenile fearfulness and adult FP but they did find a genetic correlation. They concluded that breeding programs could potentially select for reduced juvenile fear responses (e.g., shorter tonic immobility durations) but that this would be far less effective than direct selection against FP.

Correlated traits have also been studied in a separate population of birds which were selected for production-related traits but then found incidentally to differ also in their FP behavior (Riedstra and Groothuis, 2002; Rodenburg and Koene, 2003; Van Hierden et al., 2002). These birds also show positive associations between FP and locomotor activity (Rodenburg et al., 2004) and altered serotonin turnover in the severe peckers (Kops et al., 2013). Increased activity is a trait that lends itself to automated monitoring. The finding that it is associated with FP in more than one line raises the possibility of targeting this response in commercial selection programs.

With an increasing ability to detect differences in gene expression between FP and non-FP birds (Brunberg et al., 2011; Wysocki et al., 2013), new traits and targets for selection may be identified in future studies. One area of particular interest is the shared relationship between genetic markers of immune function and feather pecking traits in commercial strains (Sun et al., 2013). With the rapidly increasing potential for genomic selection, which does not depend on classical phenotypic information, and also the promise of emerging gene editing capabilities (Nicol, 2015b; Jensen, 2018) the technical barriers to selection for complex traits are greatly reduced. The feasibility of selecting birds with "naturally" tipped or blunted beaks could also be investigated. This structural trait may have fewer complicated and adverse correlations with productivity than FP behavior itself (Nicol, 2015b).

9.3.2 Social or indirect effects

The relationships that exist between productivity and FP mean that the traditional selection of birds for individual high production traits may inadvertently and paradoxically lead to reduced overall production on commercial farms, as FP victims are unable to reach their productive potential (Rodenburg et al., 2010a). A group selection approach to this problem has therefor\e been advocated and trialed experimentally with promising results (reviewed in Rodenburg et al., 2013). This approach considers the impact of inherited social effects, sometimes called associative or indirect genetic effects (Muir et al., 2014) on the group as a whole. In other words, the extent to which the behavior of one bird impacts on the performance of others can be taken into account.

A notable program in the United States selected white Dekalb birds based on their performance as a group (egg mass and mortality) over nine generations (Cheng and Muir, 2005; Muir, 1996). After five generations, mortality due to all forms of IP had decreased from 60% to 9%, even though the birds were kept under challenging conditions in cages with intact beaks and in full light (Muir et al., 2014). Based on the methods pioneered by Muir (1996), Ellen et al. (2008) developed a selection program to reduce bird mortality in which information from the (individually housed) selection candidate was combined with information from its siblings housed in family groups. The selection program proceeded by devising algorithms to optimally weight social versus individual merit. Including the indirect genetic effects increased the total heritable variance for mortality (Ellen et al., 2008). When the trait of feather condition score was used rather than mortality or survival time, a strong majority of estimated total heritable variation was due to indirect effects (Brinker et al., 2014). Application of this group method of selection has led to progressive reductions in mortality (Bolhuis et al., 2009; Rodenburg et al., 2010a, 2013) even in birds known to have a propensity for cannibalistic pecking (Alemu et al., 2016). In addition, in lines where FP is associated with fearfulness (Nordquist et al., 2011), the same selection strategy has led to reductions in fearfulness and stress sensitivity (Rodenburg et al., 2013). The tools required to integrate social effects into breeding programs are available but the successful adoption of these methods commercially faces a number of further challenges.

9.3.3 Will genetic selection solve the problem of injurious pecking?

Partnerships between commercial companies and academic groups show that it is feasible to select for reduced FP directly, or for reduced mortality associated with SFP, VP, and cannibalistic pecking. But there are additional challenges of adopting these strategies commercially. For example, further work is needed to establish the genetic × environmental interactions that affect indirect or social traits, and the extent to which results obtained from birds kept in relatively small experimental groups can be applied to situations where birds are kept commercially in groups of many thousands is not yet clear (Ellen et al., 2014). The deeper question is whether (or which of) the breeding companies that produce commercial strain birds also desire to prioritize a reduction in FP as a trait for selection in their breeding models. Commercial confidentiality also means that nothing is published on the actual content of the breeding models in current use, although companies such as Hendrix Genetics are actively engaged with academic partners in exploring these questions (Alemu et al., 2016; Ellen et al., 2014). However, because breeding companies produce laying birds for a global market where the majority of birds are currently beak-trimmed and kept in conventional battery cages, selecting robust birds with low FP tendencies for furnished cage and noncage systems may be of relatively minor commercial importance. So it is far from clear whether a genetic solution to the problem of FP is just around the corner or a far more distant prospect. Given this situation we have to consider whether improved management and bird husbandry could be sufficient to reduce the risk of FP to the point where it is safe to keep hens with intact beaks.

9.4 Management approaches

Research on management approaches has focused primarily on FP because VP and cannibalistic pecking do not tend to occur at all in chicks or pullets and outbreaks of these behaviors are unpredictably sporadic in adult birds.

It is increasingly clear that any management approach must start by considering the parent flocks that supply the laying strain chicks, and then the early life experiences of the chicks and pullets. Positive correlations exist between FP during the rearing period (or at the point where pullets are transferred to the laying facility) and FP observed during the laying period (Huber-Eicher and Sebö, 2001; Lambton et al., 2010). It is therefore likely to be commercially beneficial to implement management strategies during the rearing period that result in adult birds with low pecking tendencies. However, although the behavior of the adult hens is influenced by early experiences, it is not determined by these. The environment and management of the adult laying flocks is also critically important. The problem is best regarded as a chain of dependent steps.

9.4.1 Management of the parent flock

So far, there has been only one study of the influence of commercial parent flocks on the subsequent behavioral development of their offspring. Since chicks are reared without their parents, the mechanisms of any such effects are likely to reside in hormonal influences on egg composition, although epigenetic effects cannot be ruled out. de Haas et al. (2014a,b) studied 10 parent flocks and the development of their offspring in 47 rearing flocks. They found that in Dekalb white birds (although not in a brown strain), high levels of maternal corticosterone and whole-blood serotonin were significantly and positively associated with offspring fearfulness and SFP. The effects appeared to persist in chicks of 5 weeks of age but faded somewhat as the chicks grew older. This finding suggests that further research into management of parent flocks, with the aim of reducing stress levels, could have beneficial effects in reducing the probability of FP in their offspring. There is a paucity of evidence in this important area.

9.4.2 Management of chicks and pullets

A number of management factors are known to influence the development of FP in young chicks and pullets. Ideally good quality litter should be present during the rearing period as chicks may develop preferences for pecking substrates at an early age (Nicol, 2015b; Schwean-Lardner, Chapter 3). Poor quality substrates for chicks increase early feather pecking (Chow and Hogan, 2005; Huber-Eicher and Sebö, 2001) as well as later adult pecking tendencies (de Jong et al., 2013a; Nicol et al., 2001). de Haas et al. (2014a) found that temporary removal of litter or the provision of limited amounts of litter during the first 4 weeks of age led to increased SFP (& GFP) at 5 weeks of age. Temporary litter removal additionally increased feather damage, fearfulness, and whole-blood serotonin levels during rearing. In contrast, further enrichments to a basic litter substrate (by making it deeper, or adding grain) have not always led to further reductions in FP (Hartcher et al., 2015a).

Gilani et al. (2013) studied 34 commercial flocks (comprising 8 different breeds) and found that flocks with a higher percentage of available litter area during the rearing period had a lower percentage of missing feathers at 16 weeks of age.

Environmental conditions, particularly higher sound levels, were also strongly associated with an increased chance of SFP and plumage damage. However, experimental and epidemiological studies have found no adverse effects of higher rearing light intensities either during the rearing period itself (rearing intensities 10 lux vs 3 lux, Kjaer and Sørensen, 2002) or subsequently at lay (rearing intensities 70 lux vs 5 lux, Hartini et al., 2002), or of longer durations of the light period (Gilani et al., 2013).

Perches provided during rearing reduce the risk of FP (Gunnarsson et al., 1999; Huber-Eicher and Audigé, 1999) possibly because pullets are more able to avoid pecking conspecifics if they can use vertical structures to escape. Other risk factors during rearing include the use of bell drinkers (which can make the litter wet and thus less suitable as a foraging substrate) (Drake et al., 2010) and high stocking densities (Bestman et al., 2009). Another influential factor is a high number of diet changes during the rearing period (Gilani et al., 2013). The type of vaccination given to pullets may also need to be considered, as stimulation of a strong humoral immune response in pullets was associated with adult FP (Parmentier et al., 2009).

It is important not to forget that commercial domestic chicks are hatched in large incubators and reared without a mother hen. In the natural situation, chicks spend a large proportion of their time resting under and gaining warmth from their mother, in relative darkness. Brooded chicks are less likely to show SFP than nonbrooded chicks, and these effects can persist into adulthood (Shimmura et al., 2015). Dark brooders are devices which mimic these conditions by providing heat under a canopy of dark fringes. Dark brooders have been shown to synchronize chick behavior (Riber et al., 2007) and reduce FP (Gilani et al., 2012; Jensen et al., 2006; Riber and Guzman, 2016), possibly because active chicks do not encounter and direct exploratory pecks at resting chicks, but direct their active pecking behavior toward the floor substrate. Introduction of dark brooders on commercial rearing farms has been highly successful (Gilani et al., 2012). Compared with controls, flocks reared with dark brooders performed significantly less SFP and had lower proportions of birds with missing feathers. The benefits of simulating other aspects of maternal care are now being investigated. It has been shown, for example, that playback of maternal calls can buffer stress responses in chicks (Edgar et al., 2015) but the longer term effects of such manipulations on adult FP have not yet been studied.

9.4.3 Transfer from rearing facility to laying facility

It is generally advantageous to rear hens in an environment similar to the one in which they will live as adults (Janczak and Riber, 2015). However, similarity in environment is not the sole factor operating. One study of free-range and organic farms in the United Kingdom found that the number of changes (feeder type, drinker type, and light intensity) between rearing and laying facilities had no effect on FP, but SFP was delayed if rearing and laying accommodation was provided on the same farm (Drake et al., 2010). If birds must be transferred between farms then an earlier transfer can be beneficial in reducing plumage damage (Bestman and

Wagenaar, 2003). Early transfer may help pullets adapt to new housing before they come into full lay.

9.4.4 Management of adult hens

Although rearing conditions are important in influencing the pecking propensities of young birds, they do not fix them immutably. The predominant influence of dietary factors on the occurrence of SFP was reviewed earlier but the provision of a high quality substrate to promote adult bird foraging behavior is also highly protective against FP, whether litter was experienced during the rearing period or not (de Jong et al., 2013a,b; Nicol et al., 2001). A good pecking substrate can reduce FP in birds housed in furnished cages (Huneau-Salaün et al., 2014) as well as in birds kept in noncage systems. Adult birds devote nearly 50% of their time to foraging activities and the more this can be directed toward litter substrate materials and away from other birds the better, as there is an inverse relationship between foraging behavior and FP (Klein et al., 2000). Chickens forage for longer when in enriched environments where suitable substrates are available (Klein et al., 2000; Nicol et al., 2001). A wide range of materials is accepted and used for foraging, with peat, sand, and wood-shavings often favored (reviewed by Weeks and Nicol, 2006). However, there has been little research to evaluate whether some foraging materials are more successful at preventing FP than others. Adult hens provided with hay bales showed only a tendency to reduced GFP (Daigle et al., 2014) with no effects on SFP. Irrespective of the nature of foraging material, it needs to be maintained in a dry and friable condition to permit foraging activities. When more effort is invested in keeping litter dry and friable overall levels of FP can be reduced (Lambton et al., 2013).

Restricting birds to wire or slatted areas of the laying house for some days or weeks after transfer (to reduce the problem of birds laying eggs in places other than the nest boxes) was shown to be a significant risk factor for SFP in two epidemiological studies (Lambton et al., 2010; Nicol et al., 2003). The most likely explanation for this is that access to important foraging material is prevented by this practice. However, a small-scale study of 6 groups of 100 white birds, feather cover was actually improved in the three groups that were restricted from litter for 2 weeks after transfer (Alm et al., 2015). Under some circumstances there may therefore be benefits in keeping newly transferred birds close to important resources such as food, water, and nest boxes. An optimal solution may be to allow newly transferred birds to access the litter area for just a few hours each afternoon. This suggestion has been trialed informally by farmers participating in studies at the University of Bristol (www.featherwel.org) but scientific studies to determine the effects of this suggestion on all aspects of bird welfare would be useful.

The provision of an outdoor range improves plumage condition for birds kept in aviary systems (Heerkens et al., 2015) and for free-range and organic birds access to the range provides another management strategy to reduce FP. If the range is well-used, with a high proportion of birds venturing outside, then this greatly reduces the risk of SFP and plumage loss (Green et al., 2000; Lambton et al., 2010;

Nicol et al., 2003) as foraging opportunities are greatly expanded and stocking densities greatly reduced. Unfortunately, range use is often rather poor, with an uneven distribution of birds clustered adjacent to the house. Factors influencing range use have recently been reviewed and this knowledge could be used to develop strategies to encourage greater, and better, use of the range (Pettersson et al., 2016).

Studies of adult birds show that SFP and mortality are increased under high indoor light intensities (e.g., 30 lux vs 3 lux, Kjaer and Vestergaard, 1999; 50 lux vs 5 lux, Mohammed et al., 2010), in contrast to the rearing period where high light intensities and durations seem to be well tolerated. These effects can start during the early laying phase, as detected in the farm surveys conducted by Drake et al. (2010), where higher light intensities at 17–20 weeks were associated with an earlier onset of FP. This is a paradoxical finding as increased range use will also be associated with exposure to vastly higher light intensities, and yet the protective effects of range use appear to far outweigh any counter-influences. Because of concerns about high internal light intensities, farmers often prefer to house hens under low light intensities. Long-term housing under low light conditions can provoke other welfare problems including eye problems, difficulties in judging flight distances, and disruption of social recognition (reviewed in Nicol et al., 2013) to the point where minimum light intensities have been set to protect bird welfare (e.g., at 10 lux in farm assurance guides, RSPCA 2013). In the early laying phase, low light intensity can also reduce egg production (O'Connor et al., 2011). However, if outbreaks of FP do occur, then the first response of most farmers is to reduce light intensity and/or to use specific wavelengths to diminish the birds' perception of conspecifics' feathers (Nicol et al., 2013).

The complex influences of flock size and internal stocking density are not yet understood. In relatively small-scale experimental studies FP was found to increase with stocking density (Nicol et al., 1999) but subsequent work with large flock sizes found an opposite effect (Zimmerman et al., 2006). No clear relationships between flock size and FP have been found in many studies of commercial flocks (Gilani et al., 2013; Green et al., 2000; Gunnarsson et al., 1999; Lambton et al., 2010; Oden et al., 2002) and other aspects of bird management overshadow simple flock size and density effects (Zimmerman et al., 2006). However, the relationship between stocking density and competition for resources such as perch or trough space must also be considered. In a study of organic flocks it was this increased resource competition at higher stocking densities that was thought to be responsible for greater plumage damage in birds kept in aviary systems at stocking densities of between 6 and 12 hens/m^2 floor area (Steenfeldt and Nielsen, 2015).

Poor health status of adult birds is often associated with FP, although cause and effect relations are not always clear. FP is associated with red mite infestations (Heerkens et al., 2015), egg peritonitis and infectious bronchitis (Green et al., 2000) and, if skin is damaged, with skin-borne infections such as erysipelas (Nicol, 2015a).

VP is a problem that only arises during the laying period, as exposure of the cloacal mucosa during egg laying can stimulate pecking at this region (Savory, 1995).

To avoid VP it is a sensible precaution to arrange perches and other elevated structures so that the vent region of perching birds is not easily accessible to their conspecifics.

Scientific knowledge is all very well but, by itself, it will not necessarily lead to change in on-farm practices. In recognition of this gap, Lambton et al. (2013) summarized the scientific information available at the time and used it to devise 40 feasible management strategies that could be applied on commercial farms. The strategies were devised in consultation with industry representatives and other stakeholder bodies. For example, the protective effect of good range use was used as the basis for suggestions to encourage more birds to use the outdoor area, such as letting the birds out earlier, providing wide pop-holes to increase visibility of the range from inside the house, and providing shelter or other animals on the range to encourage birds out. The effectiveness of the strategies was then established in a long-term study of 100 commercial flocks. This revealed that employing a greater number of management strategies was associated with a reduced rate of GFP and SFP and improved plumage condition. The management strategies were made available to all farmers via a booklet and a website (www.featherwel.org).

9.5 Managing intact-beak flocks

Compared with noncage systems, furnished cages provide an increased possibility of containment should an outbreak of FP occur. Keeping birds with intact beaks may be easier in this system than in a noncage house where many thousands of birds can interact. Early results with intact-beak birds kept in small-group furnished cages were indeed considered positive, with mortalities ranging between 2.9% and 9% in UK studies (Appleby et al., 2002) and between 4.9% and 6.5% in Swedish studies (Tauson and Holm, 2005) and with no recorded mortality to 60 weeks in small-scale laboratory trials in the United States (Pohle and Cheng, 2009), although French results were far less encouraging (Guesdon et al., 2006). However, furnished cages have evolved, and they now generally house 60−110 birds/cage. Despite this, mortality levels for beak-trimmed birds have been falling as experience with this system grows and mortalities above 4% or 5% would now be considered poor (Huneau-Salaün et al., 2011; Sherwin et al., 2010). A direct comparison of intact- and beak-trimmed birds in large furnished cages was conducted in New Zealand in a 47,000 bird facility. At 70 weeks of age, mortality in the furnished cages was slightly higher for intact-beak birds at 3.25% (flock 1) or 2.66% (flock 2) than for beak-trimmed birds at 2.46% (flock 1) or 1.90% (flock 2) (Craig and Christensen, 2010). To place these results in context the mortality of the intact-beak birds in the furnished cages was lower than that of similar beak-trimmed birds housed in conventional cages or in free-range systems (MAF, 2010). Reports from other countries also suggest that intact-beak birds can be kept in furnished cages with low overall mortality (e.g., 2.26% in Norway, cited in Janczak and Riber, 2015).

Despite the advantages of bird containment, furnished cages provide relatively few opportunities to distract and occupy birds. The provision of ropes, mats, and beak blunting boards had no significant effect on the mortality or plumage condition of intact-beak birds (Morrissey et al., 2016) but scattering wheat bran on the pecking and scratching mat of commercial furnished cages significantly reduced mortality in intact-beak birds housed in furnished cages from 10% to 6.8% (Huneau-Salaün et al., 2014). There certainly appears to be the potential for birds to be kept with intact beaks in furnished cage systems.

The situation for birds in noncage systems is more complex. It should be easier to distract and occupy birds, but extensive damage could arise if FP arises and spreads throughout the flock. Most of the scientific research that might help has been conducted with beak-trimmed birds so it is essential to ascertain whether the findings are sufficiently robust and effective to reduce the risk of FP behavior and resultant injury in intact-beak birds. Nearly all organic birds are kept with intact beaks and also (in the United Kingdom) are flocks that supply a few niche retailers. However, although these systems are generally considered to be high-welfare, close analysis shows that the mortality levels of intact-beak and organic flocks can sometimes be significantly higher than that of birds in other systems (Weeks et al., 2016). It is essential that the so-called high-welfare systems maximize the physical health as well as behavioral freedom of their birds. If small, specialist flocks could routinely achieve low mortalities, this would provide a positive example for those farmers with larger commercial flocks, who might be keen to consider phasing out beak trimming but who are wary of the potential consequences.

A recent trial designed to consider the likely implications of a ban on beak trimming in the United Kingdom for both small and large noncage flocks was commissioned by the UK government in 2012. Twenty noncage flocks were recruited to assess whether the management strategies studied by Lambton et al. (2013) and known to decrease the risk of FP in beak-trimmed flocks would be sufficient to negate the risk of FP in intact-beak flocks. No problems were detected in intact-beak flocks during the rearing period, but outcomes during the laying period were highly variable (Nicol, 2015a). Study flocks that had been preceded by a previous intact-beak flock showed a significant improvement in end of lay mortality and plumage condition—the additional costs of the management strategies were outweighed by improved margins on these farms. However, study flocks that had been preceded by a previous beak-trimmed flock showed no significant difference in end of lay mortality or financial performance. In these flocks, it appeared that the positive effects of the management strategies were countered by the increased risks of making the transition from beak-trimmed to intact-beak birds (Nicol, 2015a). On a more positive note, this study does suggest that increased experience with intact-beak birds combined with the uptake of scientifically validated management strategies can enable noncage flocks to be kept humanely with intact beaks. A similar conclusion could be drawn from the development of the Rondeel system in the Netherlands, where scientific principles have been combined with ongoing field trials to find ways of successfully managing intact-beak flocks (Spoelstra et al., 2013).

9.6 The role of farmers and consumers

However good the science, it is unlikely that farmers will change their practices overnight. Investigating the constraints and obstacles that farmers face, or perceive that they face, is thus another important piece of the jigsaw. Palczynski et al. (2016) conducted in-depth interviews with farmers who had been involved in taking part in management strategy studies to find out more about their attitudes toward IP and the social, time, and economic factors that shape their management decisions. Farmers varied considerably in how acceptable they found photographs of different levels of plumage damage, and in their perception of the magnitude of the problem posed by IP (more than half considered it to be only a “moderate” problem), but they were all either implementing or keen to implement additional management strategies to reduce problems in their own flocks. The most popular strategies were simple pecking distractions and there was a general reluctance to adopt time-consuming strategies or those perceived to increase the risk of other problems such as floor eggs.

Consumer attitudes also have a role in nudging the farming community, or in providing a marketing opportunity. Bennett et al. (2016) analyzed 257 responses to a postal questionnaire sent to a stratified sample of UK consumers to assess their reported willingness to pay a bit more for eggs to help farmers tackle the problem of IP using appropriate management strategies. Beak trimming was not presented as a strategy in this study. Respondents were briefed with information about IP, the costs of the management strategies that might prevent it, and the prevailing price context for free-range egg sales. Overall, respondents indicated a willingness to pay 3.4% above the prevailing price for free-range eggs. The most striking finding was that the majority of respondents were shocked to discover that IP was a problem in free-range flocks, with many indicating that they felt betrayed. Given that many consumers also have a negative view of beak trimming (reviewed above) the industry will in the long run have to develop alternative ways of preventing and managing feather pecking and cannibalistic behavior.

9.7 Conclusion

The body or work reviewed earlier shows that both FP and beak trimming have negative effects on bird welfare, and that educated consumers are unlikely to tolerate the occurrence of either phenomenon in the longer term. Breeding programs and scientific research on bird management should continue to search for solutions that will enable intact-beak birds to be kept without other detriments to their welfare. This will not be easy because the low-hanging fruit has already been picked, i.e., the easier strategies such as providing food as mash rather than pellets have largely been adopted. Other changes that could substantially reduce the risk of FP (e.g., maintaining good litter condition) are perceived as difficult, or are considered to have drawbacks (e.g., reducing the number of diet changes could result in less optimal growth or production, allowing birds immediate access to litter and range as they come into lay could increase the number of floor eggs). It is essential that a holistic approach is taken when translating scientific findings into management advice to overcome these real or perceived barriers. For example, farmers could be encouraged to use compressed wood chip bedding on damp areas of litter as this is easier than raking and turning the substrate, to introduce diet changes gradually with additional pecking materials provided at these critical times, and to allow laying hens early access to litter or range during afternoon periods when most eggs will have been laid rather than all day. On-farm testing and re-evaluation of the benefits of such strategies on commercial farms should lead to continued reductions in the prevalence and incidence of feather pecking, which in turn should increase confidence in abandoning the practice of beak trimming.

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Sustainability of laying hen housing systems

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10.1 Introduction

There is increasing emphasis on improving the sustainability of animal agriculture, with consideration not just for the projected growth in global demand for foods of animal origin but also for the environmental and social impacts of various animal production practices. Because many multi-national food retailers are emphasizing sustainability as a core element of their social responsibility programs, it is becoming a key driver of their purchasing decisions for many products, including animal products. The term sustainability is often used in an environmental context. However, it actually encompasses many other kinds of concerns (NRC, 2015). While animal welfare is certainly considered as one important element of the sustainability of animal agriculture, the challenge is to balance the quality of life for agricultural animals against other key sustainability considerations for food production, such as food security and affordability, food quality and safety, environmental impacts, and the health and economic security of rural communities and agricultural workers (Niles, 2013).

Tucker et al. (2013) and Place (2018) provide some examples of the ways in which animal welfare can align with other sustainability considerations, and where it is sometimes in conflict. For example, appropriate animal handling not only reduces stress and injury to the animals, but can improve the quality and safety of their meat while also reducing production costs. Similarly, reducing animal mortality contributes positively to animal welfare and reduces environmental impact. In contrast, some more extensive production systems that meet consumer expectations for providing animals with space and behavioral freedom can have negative effects on the environment and food affordability. In this chapter, we discuss the sustainability aspects of different laying hen production systems, from the perspective of hen welfare, environmental considerations, worker health and safety, economics, and food safety.

10.2 Hen production systems

An overview of the configuration and management of different hen housing systems, along with pictures of those systems, is provided in Chapter 1 (Karcher and Mench). They can be broadly divided into cage systems and noncage systems. Conventional cages (sometimes referred to as “battery” cages) are small wire cages

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holding around 5–10 hens, with automated feeding and watering and a sloped floor to allow eggs to roll to an egg collection belt. Manure drops through the floor of the cage either into a storage pit in the hen house or onto a manure belt that conveys it out of the house. Furnished (or enriched) cages are distinguished from conventional cages in that they contain perches, a nesting area, and often a scratching area. Newer designs of furnished cages are also larger than conventional cages, typically housing 60–100 hens. As with conventional cages, feeding, watering, and egg collection are all automated; manure is always removed via a belt after it drops through the cage floor in furnished systems (Fig. 10.1).

Noncage systems are considerably more variable than cage systems, but the design of all indoor noncage systems is such that hens can freely move throughout the barn. When ideally configured, noncage systems include sufficient perching space for all hens, a littered area that is sizable enough to accommodate foraging and dustbathing behavior, and nests. Barn (or floor) systems are mainly on one level, although there may be a raised slatted area in the house with nests. Aviaries are multi-level systems (see Fig. 10.3). There is a littered floor, and perches, nests, feeders, and waterers are arranged in the tiers of the aviary. Aviary tiers are typically made of wire, and some aviary designs have doors on the tiers that can be used to enclose the hens (e.g., at night, or for training to use nests and find feed, water and perches after they are introduced to the system), and thus are somewhat of a hybrid between a cage and a noncage system.

Any noncage system can provide outdoor access to pasture to the hens, in which case it is considered a free-range system. Also, systems exist where hens do not have unrestricted outdoor access but where they do have access to a covered veranda, with the sides also covered with bird-proof mesh. Alternatively the hens can be mainly housed on pasture (pasture-based production), although they are typically given access to a house-like structure at night to protect them from predators. Free-range and pasture-based systems can also be classified as organic, provided they meet local standards for configuration and management (such as related to the provision of only organic feedstuffs and restrictions on the use of particular compounds to prevent or treat disease).

Flock sizes in noncage systems can range from hundreds (for example in small-scale pastured production) to tens of thousands (in large-scale commercial aviaries) of hens. Feeding, watering, and egg collection are typically automated, except in some small-scale production situations. Larger indoor noncage systems have manure belts under the tiers or slatted areas, but manure is also deposited in the litter and this manure usually remains in the house throughout the entire production cycle.

Collectively, noncage systems and furnished cages are sometimes referred to as "alternative" systems because they represent alternatives to the most prevalent housing system, conventional cages. Globally, cage systems (and presumably mainly conventional cages) are the predominant egg production method in all major egg producing countries/regions except the EU-15 (IEC, 2016). For example, more than 90% of egg production in three of the largest egg producing countries (China, Japan, and United States) comes from caged hens, and that figure is 100% in four

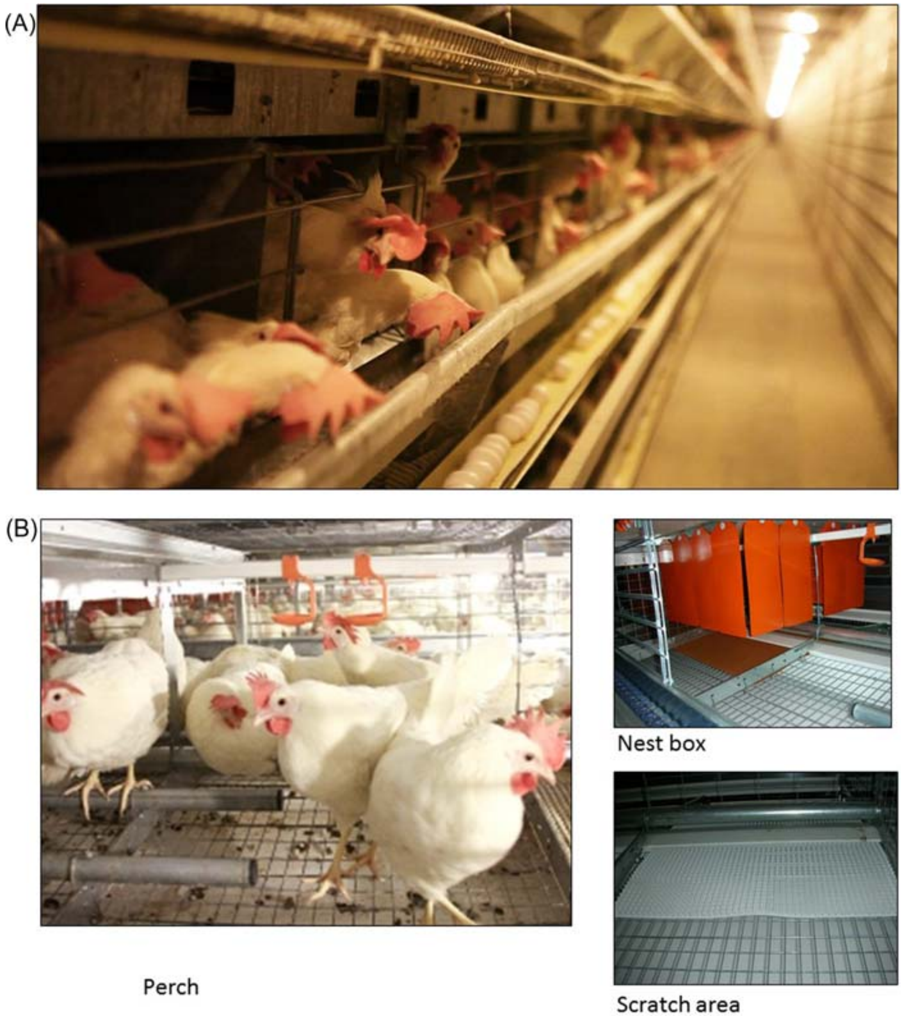

Figure 10.1 Cage systems. The top picture (A) shows a conventional cage, while the lower picture (B) shows an enriched colony cage (Big Dutchman Avech II) containing perches, a nesting area, and a scratch pad.
Source: Photographs courtesy of the Coalition for Sustainable Egg Supply (CSES); schematics and video walk-throughs of these systems (as well as an aviary system) can be found on the CSES website http://www2.sustainableeggcoalition.org/.

of the other largest producing countries (Turkey, India, Russia, and Mexico). The divergence from this is striking in the EU-15, where conventional cages have been banned and where the systems used show significant variation from one country to another depending upon factors like consumer and customer preference and export markets (Fig. 10.2).

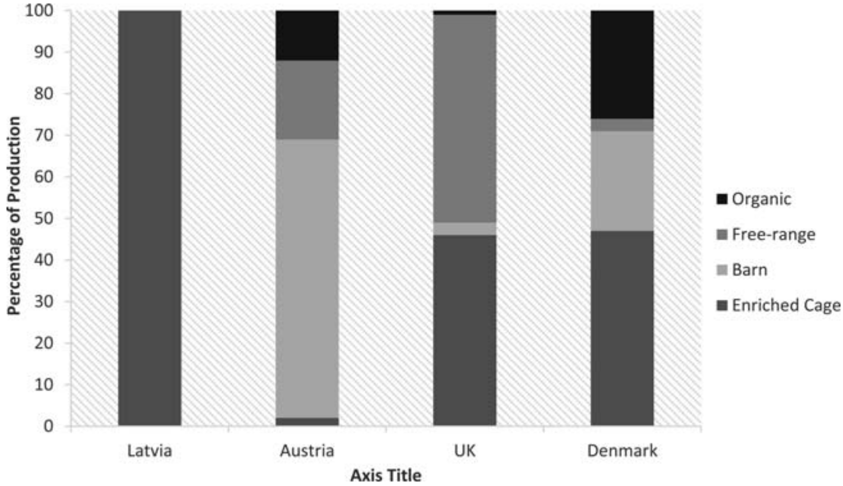

Figure 10.2 Proportion of different laying hen production systems in selected countries in the EU, illustrating the divergence that has occurred since the implementation of the EU ban on conventional cages effective in 2012. In Latvia, nearly all layers are kept in enriched cages; production in Poland, Portugal, Spain, and Estonia is also mainly from enriched cages. In Austria the predominant system is the barn system, and only a very small proportion of hens are kept in enriched cages; Sweden and The Netherlands are similar. The United Kingdom has the highest proportion of free-range production in the EU, with most of their remaining production coming from enriched cages, while Denmark has the highest proportion of organic production, with nonorganic eggs produced both in barn systems and enriched cages. See Windhorst (2017) for these and additional data.

It is important to realize that alternative systems can still be considered in many ways to be in a developmental phase, undergoing innovations in both design and management as egg producers gain more experience with them and are able to identify challenges that need to be addressed. In the sections that follow, we summarize current evidence related to sustainability for each system and provide a systems comparison. We note that we do not explicitly include comparisons with organic egg farming or other emerging egg production practices (e.g., agroecological), which differ from the systems discussed herein primarily in terms of how they are managed rather than how they are designed.

10.3 Hen welfare

Hen welfare is the most-researched area of the different sustainability topics, and the impacts of production systems on hen welfare have been the subject of a number of comprehensive reviews (Lay et al., 2011; Rodenburg et al., 2012; and see reports from the Laywel project, http://www.laywel.eu/ as well as the other chapters in this volume). Concerns about animal welfare are considered to fall into three broad areas (Fraser et al., 1997): expression of normal behavior, satisfactory functioning (which includes health and production), and feelings (affective states). In general, restriction of highly motivated behaviors and health conditions results in negative affective states (pain, distress, or frustration), and as such we will focus here on the key behavioral and health issues that constitute risk factors in the different housing systems. This is not to say that other aspects of affective states (e.g., fear, pleasure) are not of importance, but their relationship to egg production system is less investigated.

10.3.1 Behavior

10.3.1.1 Restriction of normal behavior

As mentioned earlier, conventional cages have fallen into disfavor in several areas of the world because of the behavioral restrictions they impose on the hens. First, there is an insufficient space for free movement, although hens can make most of their basic postural adjustments, as long as the cage is not overstocked (Mench and Blatchford, 2014). Second, conventional cages lack the resources necessary for the hens to perform their highly motivated behaviors. Research has focused mainly on three behaviors: nesting, perching, and use of loose material for behaviors such as foraging and dustbathing (see Nicol, 2015; for a recent detailed review of laying hen behavior). Hens will work (a sign that they are highly motivated) to obtain access to a nest when they are about to lay an egg, and show signs of restlessness or agitation when a nest is unavailable. They will similarly work to obtain a perch and make extensive use of perches at night if these are provided. Perching has the additional benefit of improving bone strength. Nesting and perching are both behaviors that are of evolutionary importance for fowl, providing protection (for nestlings on the one hand, and older birds on the other) from predators. Because of their evolutionary importance, these behaviors are highly conserved even in fowl that have been domesticated for thousands of years.

In the wild, foraging behavior takes up a significant proportion of a chicken's day. Although caged hens do not need to forage in order to obtain adequate nutrients, this is also a highly conserved behavior. In addition, lack of adequate foraging opportunity can lead to problems with feather pecking (see Section 10.3.1.2). Although it has been suggested that dustbathing is not a "need" to the extent of these other behaviors, it does help to maintain good plumage condition by reducing feather oiliness.

Furnished cages represent an attempt to overcome some aspects of behavioral restriction while still maintaining some of the health and production advantages of conventional cages. As compared to noncage systems, however, movement is still restricted, since the cages allow only local movement rather than large-scale movement (e.g., flight). And while most research indicates that the perches and nests are well-used, the "scratch" area appears to be inadequate to fully stimulate foraging and dustbathing because of the lack of appropriate loose material and the relatively small size of the area devoted to these behaviors (Guinebretière et al., 2015; Louton et al., 2016).

10.3.1.2 Abnormal behavior

The most serious abnormal behaviors performed by hens are severe feather pecking and cannibalism (tissue pecking). Both cause injury to other birds and, in the case of cannibalism, can lead to high flock mortality. Many factors can contribute to the development of these problems, although inadequate foraging opportunities and nutritional deficiencies are key (Nicol, Chapter 9; Rodenburg et al., 2013). In general, flocks in noncage systems are at higher risk of damage as a result of outbreaks of severe feather pecking and cannibalism than hens in caged systems, because these behaviors can spread rapidly through larger flocks. In addition, the high ambient light levels in free-range and pasture-based systems can contribute to outbreaks.

The current solution to these problems is to beak trim the hens. However, this is a welfare problem in its own right, since it causes short-term pain and, if not properly conducted, can also cause beak malformations that have other negative effects on welfare. For this reason several European countries have either banned, or are considering banning, beak trimming. Potential alternative solutions for controlling feather pecking and cannibalism are currently under investigation, although their implementation faces challenges (Nicol, Chapter 9).

10.3.2 Health

10.3.2.1 Disease and parasitism

Hens are susceptible to a variety of viral, bacterial, and parasitic diseases, and the risk of these diseases can be influenced by production system (see reviews by Lay et al., 2011; Lister and van Nijhuis, 2012). Although these problems can occur in any system, in general the risk is higher in systems that make biosecurity more challenging (e.g., where it is more difficult to control contact between hens and disease-carrying wild birds/rodents) or that allow flocks access to contaminated soil or their own feces (Fossum et al., 2009; Permin et al., 1999).

In terms of viral disease, the most significant concerns globally are avian influenza (AI) and Exotic Newcastle Disease. According to the World Animal Health Organization (OIE, 2017), AI has been identified in 77 countries, and ongoing outbreaks led to the destruction of nearly 7 million poultry by March 2017. Newcastle disease is the major viral disease of poultry in many countries, particularly in the developing world, and causes significant poultry mortality (Wang et al., Chapter 15). Wild birds are reservoirs for both AI and Newcastle, and thus laying hens in free-range and pasture-based systems are at greater risk of infection. However, AI and Newcastle outbreaks have occurred in both cage and noncage (including backyard) flocks, emphasizing that biosecurity breaches can increase risk in any system.

As reviewed in Chapter 14 (Mullens and Murillo), laying hens can also harbor a variety of internal and external parasites and infestation can be affected by housing system. In general, cage systems facilitate bird-to-bird transmission of permanent ectoparasites (e.g., Northern fowl mites) because of the high hen stocking densities. However, cages reduce problems with internal parasites (coccidia and helminths) as compared to noncage systems because they restrict contact between the hens and their feces. In addition, alternative systems can favor temporary parasites that spend most of their life cycle off of the host. The most serious of these is the poultry red mite *Dermanyssus gallinae*, which can cause severe anemia and death in hens, and which thrives in more complex alternative systems that provide daytime harborage areas (e.g., nest boxes, perches). Severe red mite problems can also cause stress in laying hen flocks and can be related to outbreaks of feather pecking (Heerkens et al., 2015). Finally, red mites are vectors for other diseases (Mullens and Murillo, Chapter 14) including Newcastle disease and Erysipelas, the latter of which is a bacterial infection that causes extensive tissue hemorrhage and high mortality in poultry. Erysipelas has been reported to be more common in hens kept in free-range range systems than in litter-based systems, and more common in litter-based systems than in cages (Eriksson et al., 2013; Fossum et al., 2009; Mazaheri et al., 2005).

10.3.2.2 Bone health

Poor bone health that results in hens being susceptible to long bone fractures and keel abnormalities (fractures and deviations, collectively referred to as keel bone damage) is increasingly considered to be one of the most serious welfare problems in commercial flocks (see reviews by Harlander-Matauschek et al., 2015; Toscano, Chapter 8). A variety of factors appear to contribute to bone fragility, including genetics, nutrition, and production/housing environment both during rearing and lay. Hens in cage systems overall have weaker bones than hens in noncage systems due to lack of bone loading from exercise, and are highly susceptible to long bone breakage when they are handled (e.g., removed from their cages for depopulation at the end of lay); bone strength is somewhat better in furnished than in conventional cages, probably because the use of perches increases loading on the leg and wing bones. On the other hand, hens in noncage systems are reported to have high rates of keel bone damage, apparently resulting from falls, high impact collisions with housing structures, and prolonged pressure on the keel from perching. While problems with keel bone damage have been observed in all production systems the prevalence varies considerably between systems, with the incidence lowest in conventional cages followed by furnished cages, and the highest incidence in aviary systems.

10.3.2.3 Air quality

David et al. (2015a,b) recently reviewed the literature on air quality in different hen housing systems from the perspective of animal welfare. Their reviews indicated that, in general, air quality is worse in indoor housing systems where hens have access to litter (barns, aviaries). These environments are often reported to have higher levels of respirable dust, bacteria, and endotoxins than cage (either

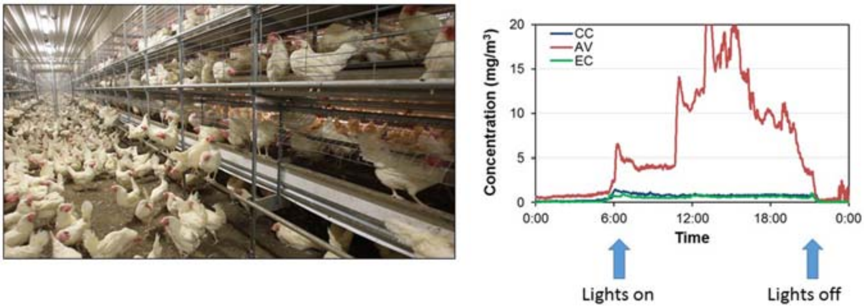

Figure 10.3 Dust is a particular problem in systems with litter, as in the aviary system shown on the left. Dust can cause respiratory problems for both hens and workers, is a factor in bacterial contamination of eggshells, and is emitted from the barn, affecting outdoor air quality. The graph on the right shows the relationship between hen behavior and dust levels (PPM10) in a study carried out in an aviary (AV) in the Midwestern United States (Zhao et al., 2015). When the lights come on at 6 AM, the hens start to become active and dust levels begin to increase. At 11 AM, the doors of the wire enclosure in the system are opened and the hens come out to forage and dustbathe in the litter, at which point dust levels increase rapidly. They stay high until the lights are turned off and the hens are once again closed in the system. Dust levels recorded simultaneously in a conventional cage system (CC) and an enriched colony system (EC) on the same farm are shown for comparison. *Source:* Graph reprinted with permission from Zhao et al., 2015; aviary photograph (Big Dutchman Natura 60) courtesy of the Coalition for Sustainable Egg Supply.

conventional or furnished) houses (Fig. 10.3; David et al., 2015a). They may also have higher ammonia levels due to the accumulation of manure in the litter (David et al., 2015b; Zhao et al., 2015), particularly during cold weather periods when the ventilation is reduced to better maintain house temperature within the thermal comfort zone of the hens. Experimental studies have shown that dust and ammonia can cause conjunctivitis and respiratory problems in hens, and also increase their susceptibility to secondary infections. However, there are significant gaps in knowledge generally about hens' physiological and behavioral responses to aerial contaminants as well as about synergistic effects of dust and ammonia on hen health in commercial environments (David et al., 2015b). As discussed later, aerial contaminants in hen houses can also affect workers and contribute to emissions that are of environmental concern (Shepherd et al., 2015).

10.3.2.4 Mortality

A recent meta-analysis of 3851 flocks in Europe revealed several system-related patterns for hen mortality (Weeks et al., 2016). Cumulative mortality was significantly lower in cage than noncage flocks, and also significantly lower in flocks that were beak trimmed than in those that were not. Although the authors did not statistically compare different types of noncage housing to one another, mortality was numerically lowest (and similar to cages) in indoor aviaries as compared to barns and systems with access to range. An earlier meta-analysis that compared published literature on 124 flocks housed in either aviaries or conventional cages (Aerni et al., 2005) found no system differences in either mortality or rates of cannibalism, and also found no effect of beak trimming on mortality despite a reduction in the prevalence of cannibalism.

Although there are many published reports of health conditions in specific production systems, there is limited information comparing the causes or incidences of mortality due to particular heath conditions between different production systems. In an on-farm survey of 13 flocks in Belgium, Germany, and The Netherlands, Rodenburg et al. (2008) found that mortality was higher in noncage (aviaries and barns combined) than furnished cage systems, with the main causes of mortality (as self-reported by farmers) being feather pecking and cannibalism, red mites, smothering, and infections. Fossum et al. (2009) conducted routine necropsies on 914 hens submitted by farmers for analysis in Sweden, and found that there were significantly higher incidences of bacterial (mainly *Escherichia coli* and Erysipelas) and parasitic (mainly red mite and coccidiosis) diseases and cannibalism in litter-based and free-range housing systems than in cages, and significantly higher rates of viral disease (mainly lymphoid leucosis) in indoor litter-based systems than in cages. An additional source of mortality reported in free-range systems is predation (Lay et al., 2011).

10.4 Environmental impacts

There are multiple facets of the environmental impacts of animal production systems, including related to consumption of nonrenewable resources (e.g., land, water, and fossil fuels) and emissions of constituents such as Greenhouse gases, ammonia, and dust. In their review of the environmental impacts of egg production systems, Xin et al. (2011) summarized data from multiple studies and identified several "knowns," including that noncage systems tend to be less efficient in resource utilization (feed, energy, and land) than cage systems and (as discussed in Section 10.3.2.3) also tend to have poorer air quality. However, they also emphasize the important role of manure management and manure application in any production system, particularly as they affect emissions and nutrient runoff to water, as well as the many areas that are currently "unknown" with respect to egg production system impacts on the environment.

Overall, the potential environmental (carbon) footprint of different production systems can be assessed using the integrative method of Life Cycle Assessment (LCA; Williams and Speller, 2016). LCA is a standardized methodology for quantifying material and energy flows and emissions across a particular product's supply chain (Fig. 10.4). Pelletier et al. (2014) used LCA to assess how the environmental impact of egg production in the United States had changed from 1960 to 2010. They found that energy use and emissions had declined significantly during this period, and that the three most important factors influencing this decline were

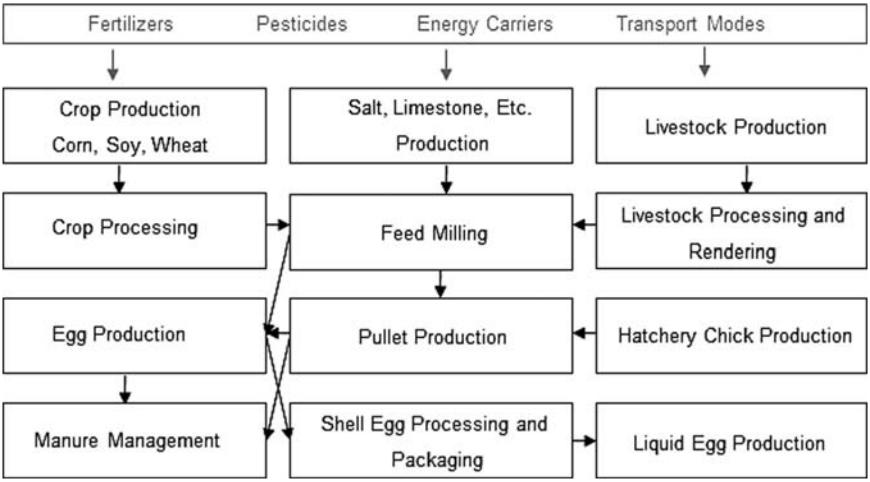

Figure 10.4 Life Cycle Assessment (LCA) involves estimating the environmental footprint of a particular process or system by quantifying material and energy flows and emissions across the supply chain. This figure shows an example of the characterization of inputs and emissions that are often included in a LCA of egg production. It evaluates not just production of eggs at the farm level, but also the production and processing of feedstuffs and raw materials, chick production, material and energy use at both the pullet and layer facilities, the processing and packaging of the eggs, and all transportation stages up to the egg processing facility.
Source: Reprinted with permission from Pelletier et al. (2013).

improved hen performance (mainly increased feed efficiency but also reduced mortality), changes in feed composition, and improved manure management; all of these factors can also vary among different current production systems, with consequent effects on their carbon footprint.

Williams and Speller (2016) review LCA carried out in different egg production systems in Europe, the United States, Australia, and Canada, with a view toward assessing relative potential environmental impact. The carbon footprint varied both between countries and systems. In general, the results indicate that cages have a lower environmental burden than noncage systems, although as the authors note it is difficult to compare these studies for various methodological reasons (e.g., different housing configurations and analysis assumptions).

However, there are some published studies that used LCA to directly compare different hen production systems, all of which indicate that cages have a lower environmental impact on some measures than noncage systems. Mollenhorst et al. (2006) evaluated conventional cages, barns with or without an outdoor run, and an aviary with an outdoor run in the Netherlands. They found that cages had the lowest acidification, eutrophication (excessive nutrients in natural water supplies due to runoff), and global warming potential, as well as the lowest land use. There were also differences among the noncage systems, for example with the aviary with the outdoor run having lower acidification and eutrophication potentials than the barn with an outdoor run, probably due to differences in manure management. Also in the Netherlands, Dekker et al. (2011) compared conventional cages, barn systems, and aviaries both with and without range access, and organic systems. Their analysis again indicated that the noncage systems had greater global warming and acidification potentials, as well as greater land occupation, than the cage system. They also found multiple differences among the cage-free systems, for example with organic having the lowest global warming potential and barn systems the lowest land use.

Similar studies have been carried out in the United Kingdom by Leinonen et al. (2012, 2014). In their initial study (2012), they compared conventional cage, barn, free-range, and organic systems. As in the studies in the Netherlands, conventional cages had the lowest global warming potential, land use, and acidification and eutrophication potentials, with the differences driven largely by feed efficiency. There were again differences among the noncage systems. For example the organic system had the highest energy use, land occupation, and acidification potential. It also had the greatest global warming potential, in contrast to Dekker et al. (2011). In their study published after the EU conventional cage ban, Leinonen et al. (2014) compared conventional cages with furnished cages, and found that the furnished cages had somewhat lower primary energy use and global warming potential, mainly due to better energy use efficiency and slightly higher hen productivity.

10.5 Egg quality and safety

Production system can affect egg quality and food safety aspects of table eggs. In furnished cages, eggs can be laid in the nest area, but also in other parts of the cage. However, all eggs in cages roll to the egg belt for collection. Specific aspects that play a role with egg quality in cages are soiling of the eggshell and damage that may occur when eggs are rolling over the cage floor. In noncage systems, group nests are available for egg laying. However, eggs can also be laid in the aviary system itself, potentially resulting in cracks, or on the floor of the house in the litter, where soiling can occur due to the manure deposited in the litter. A comprehensive recent review of production system effects on both egg quality and safety can be found in Cepero and Hernándiz (2015).

10.5.1 Egg quality

Exterior egg quality is determined by eggshell quality (e.g., strength and thickness), integrity (cracks), and soiling. There do not appear to be consistent effects of production system on eggshell quality (Holt et al., 2011; Rossi and De Reu, 2011), likely because quality is affected by so many factors besides housing system, including hen genetics, hen age, and diet composition. Similarly, egg interior quality, which comprises various properties of the albumin and yolk, appears to be affected more by nutritional factors than by production system (Jones et al., 2015;

Karcher et al., 2015; Rossi and De Reu, 2011). However, there are production system risks associated with eggshell soiling and cracking. Soiling is only an egg quality issue in countries where egg washing is not allowed, such as the European Union, although soiling can contribute to food safety risk (see Section 10.5.2 below). Cracked or soiled eggs can occur in any system but the incidence of these issues is influenced by a number of elements of system design and management (Cepero and Hernándiz, 2015), which may account for the divergent findings seen in studies comparing shell integrity in different systems (Holt et al., 2011; Rossi and De Reu, 2011).

In general, the most important factor affecting cracking and soiling in alternative systems is whether eggs are laid in nests or in another part of the system (in the litter, or on the wire or slatted areas). Nest-laid eggs are generally cleaner and less likely to be cracked than eggs laid in other parts of the system. For example, in a comparative study of egg quality in furnished cages and noncage systems, De Reu et al. (2009) found a larger percentage of eggs with cracked shells in furnished cages than in noncage systems (7.8% vs 4.1%). This was mainly caused by eggs that were laid outside the nest area in the furnished cages hitting the egg saver or other eggs at too high of a velocity. The percentage of nest eggs laid in furnished cages may depend on group size. Wall (2011) found that groups of 20 or 40 hens laid more eggs outside the nest area than groups of 8 or 10 hens and that this resulted in poorer egg quality in the two largest cage sizes. Guinebretière et al. (2012) showed that nest use in furnished cages may be encouraged by providing an attractive nest mat, such as artificial turf. They also found that eggs laid outside the nest, and especially those laid in the pecking and scratching area, were dirtier than eggs laid in the nest. In noncage systems, eggs laid on the floor are of poorer quality, mainly due to soiling with manure. Floor eggs are usually collected separately and sold as pasteurized (in liquid, frozen, or dried form) eggs. The group nests in many noncage systems are kept clean by closing the nests during the night and expelling the hens by lifting the nest floor to prevent the hens from roosting in the nests.

10.5.2 Food safety

Regarding food safety aspects linked to eggs and egg production, infection of eggs with pathogens, and particularly *Salmonella* Enteritidis, is a major concern. An egg can become contaminated with Salmonella either in the oviduct of an infected hen, or after it is laid via entry of Salmonella through the egg pores due to soiling of the shell with manure from infected hens in the flock. Salmonella can be horizontally transmitted between hens, particularly when they are in close contact with one another because of high stocking densities (Gast et al., 2014, 2017). Therefore noncage systems could be considered to pose greater risk due to egg soiling, while cage systems could increase risk due to horizontal transmission. However, evaluating Salmonella risk directly is difficult because the incidence of Salmonella in commercial eggs is so low (typically fewer than 1% of eggs sampled test positive for Salmonella, and flock outbreaks are also sporadic; Holt et al., 2011) that it is logistically challenging to test the eggs themselves for infection when systems are being compared. Environmental and eggshell bacterial loads are therefore used as a proxy for the risks of egg infection in different production systems.

Many studies have evaluated eggshell bacterial loads as a function of housing system, and in general these studies find that eggs from noncage systems have higher overall bacterial loads than those from cage systems, although the magnitude of the difference, particularly on commercial farms, is rather small (about $0.5-1.0$ log unit; reviewed by Cepero and Hernándiz, 2015; Rossi and De Reu, 2011). The greater abundance of bacteria in noncage systems is related not only to the litter (with manure) in these systems but the higher dust levels (Rodenburg et al., 2008), which can result in a higher bacterial load on the eggshell. These system differences disappear when eggs are washed, and with unwashed eggs are reduced during the time the eggs are stored. In addition, according to Rossi and De Reu (2011), it is not clear whether bacterial counts on shells reflect overall egg interior bacterial contaminationare, since most studies of egg contents have focused only on *Salmonella* spp.

Studies have also evaluated total and specific bacterial loads in different parts of the house in cage and noncage systems, and these indicate the importance not just of production system, but of where the eggs within any system are laid, in terms of eggshell contamination. Jones et al. (2015) compared conventional and furnished cages and an aviary, and found using environmental sampling that total counts of aerobic and coliform bacteria, as well as the percentage of samples highest for *Salmonella* and *Campylobacter* spp., were especially high in the aviary generally and on the scratch pad in the furnished cage (Fig. 10.5). When eggshell contamination was assessed in pooled shells, there were no differences for either *Salmonella* or *Campylobacter* spp., with levels of contamination quite low. However, eggs laid in the litter or in the system in the aviary had the highest levels of aerobic organisms and coliforms; in contrast, eggs laid in the nests in the aviary had eggshell aerobe and coliform levels that were similar to those in the conventional and enriched cages. Similarly, within furnished cages, Guinebretière et al. (2012) found that eggs laid outside the nest, and especially those laid in the pecking and scratching area, had a higher total bacterial load than those laid in the nests.

Regardless of relative risks, data do not indicate that eggs are more likely to become infected with *Salmonella enteritidis* in one production system than another. Outbreaks of foodborne illness have been linked to both cage and noncage systems, and when environmental monitoring rather than eggshell contamination is used to gauge comparative *Salmonella* prevalence the risk is sometimes found to be higher in cage systems, sometimes in noncage systems (Cepero and Hernándiz, 2015; Dewulf et al., 2011; Gast and Jones, 2017; Holt et al., 2011). This emphasizes that, like egg quality, many other factors besides housing system can affect *Salmonella* prevalence in a flock (Dewulf et al., 2011; Holt et al., 2011; Van Hoorebeke et al., 2011), including the ability to maintain good biosecurity and effectively clean and disinfect the barn/premises between flocks, seasonal factors, farm and flock size, hen age, and whether or not the hens have been vaccinated against *Salmonella*.

Sample	Av. total aerobes (log cfu/ml)	Av. total coliforms	Salmonella spp. (%positive)	Campylobacter spp. (% positive)
Aviary drag swab	7.5	4.0	69	100
Aviary nest	5.5	1.6	28	10
Aviary wire	5.3	2.1	18	74
Enriched nest	5.6	2.7	16	64
Enriched wire	4.7	1.7	16	65
Enriched scratch pad	6.8	3.8	23	93

Figure 10.5 A build-up of manure in any housing system can lead to soiling and bacterial contamination of eggs. This photograph shows a scratch pad in an enriched colony system that has become heavily contaminated with manure. If the hens lay eggs on this pad, the eggshells will become contaminated with bacteria. The table shows the results of a study evaluating environmental bacterial loads in different parts of an aviary and the enriched cage system from which the photo of the scratch mat was taken. The greatest number of total aerobic organisms and coliforms, and the highest percentage of samples with *Salmonella* and *Campylobacter* were found in drag swabs taken in the aviary and on the scratch pad of the enriched colony (the full data set can be found in Jones et al., 2015). When eggshells were analyzed in this same study, shells from both the litter floor and wire in the aviary had the highest levels of aerobes and coliforms, although there were no differences between the aviary and enriched colony samples for either *Salmonella* or *Campylobacter*.
Source: Photo of scratch pad courtesy of Coalition for Sustainable Egg Supply.

One other aspect of egg safety that deserves mention is chemical contamination. In any system of production, eggs can potentially become contaminated with organic pollutants, pesticides and heavy metals via contaminated feed, water, or pesticide application (as demonstrated recently in Europe where large numbers of eggs became contaminated with the pesticide fipronil, which had been illegally incorporated into a non-chemical red mite control agent; Poultry World, 2017). There appears to be an additional risk when hens are given access to the outdoors, however, since they can also come into contact with contaminated land. There have been recent reports of free-range eggs contaminated with dioxin-like compounds in the United States and Europe, heavy metals in Europe, and pesticides in Brazil; litter in indoor noncage systems can also have contaminants that affect egg safety (see review by Holt et al., 2011).

10.6 Worker health and safety

Although laying hen housing system design and management can have significant effects on the health and safety of the workers in those systems, there has been less research on this topic than on the other sustainability-related issues. Although there are a variety of worker exposure hazards in egg production systems (Le Bouquin and Huneau-Salaün, 2011), major areas of concern are related to ergonomic challenges and injury; zoonoses; and inhalation of dust and ammonia with consequent potential for allergies, exposure to bacterial toxins and respiratory problems. We will focus on the last two areas because of the dearth of published systematic studies on ergonomics and musculoskeletal injury in workers in different hen production systems.

10.6.1 Zoonoses

Many of the viral and bacterial diseases that affect poultry can also affect humans. In commercial laying hen production systems, the bacterial and viral zoonoses that are most likely to affect workers are AI, Newcastle disease, chlamydia (ornithosis/psittacosis), and erysipelas (Agunos et al., 2016; Dale and Brown, 2013; Hafez and Hauck, 2015). Humans infected with AI show respiratory and other flu-like symptoms, and lethality is high (50%–65%) in the case of infections with highly pathogenic forms. According to the World Health Organization (2017), there were 860 confirmed cases of human infection with one highly pathogenic form (H5N1) of the AI virus between 2003 and 2017, with 454 deaths. The most significant public health concerns are in parts of Africa and Asia (especially China), where both low and high pathogenic strains are endemic (OIE, 2017). The other viral and bacterial zoonoses, while still of concern, do appear to pose less risk to workers because their prevalence is low or they cause less severe symptoms in humans than they do in hens (Agunos et al., 2016).

External parasites of poultry can also affect workers, even though humans are not the natural hosts of these parasites. Cases of dermatitis have been reported from

Northern Fowl mites (Agunos et al., 2016), and mite infestations can also contribute to worker respiratory problems (see below). Of particular concern is the poultry red mite, *Dermanyssus gallinae* (George et al., 2015). Red mites will bite humans and consume blood and can cause dermatitis, and are considered vectors for other zoonotic diseases, including Newcastle, encephalitis, and erysipelas.

Workers in poultry houses are susceptible to zoonoses because transmission to humans occurs mainly through close contact with infected birds (e.g., handling birds or contaminated equipment/eggs, inhaling contaminated air, and contact with live vaccines during administration to the birds). However, there is currently little evidence that problems with viral and bacterial zoonoses are associated with particular laying hen housing/system types, although the risk factors in some environments are greater than in others. Chlamydia, for example, which is an emerging worker health problem in Europe (Lagae et al., 2014), is spread via inhalation of contaminated feathers and fecal material, suggesting that environments where manure is kept in the house and mixed with material that creates dust (as in indoor noncage environments) would potentially increase risk. In addition, as discussed earlier red mite infestation is more prevalent in noncage than cage systems, and also more prevalent in furnished than conventional cages, indicating that the risk to workers is lowest in conventional cage houses.

10.6.2 Dust and ammonia

The inhalation of "poultry" dust (from feathers and skin, dried manure, feed, litter material, and other residues) increases the risk of workers in laying hen facilities developing respiratory problems. These problems can include allergies, asthma, chronic bronchitis, chronic airway obstructive disease (COPD), and organic toxic dust syndrome (Viegas et al., 2013). In addition, airborne particulates in poultry houses can include bacteria and viruses of zoonotic concern, endotoxins (bacterial breakdown products), and fungi, with dust acting as a mechanical vector for these contaminants. Ammonia at high levels can also cause respiratory problems and conjunctivitis in humans, and the effects of ammonia and dust are synergistic in terms of their effects on the human respiratory system.

A number of studies have evaluated the extent of worker exposure to dust and ammonia in different production systems (see Le Bouquin and Huneau-Salaün, 2011). There have also been several recent studies evaluating the effects of different hen housing systems on worker respiratory health. Kirychuck et al. (2006) compared worker exposure to dust and ammonia in floor-housing and cage systems. They found that, while there was greater exposure to both contaminants in floor-housing systems, workers in the cage systems actually reported more current and chronic respiratory systems, with one of those symptoms related to levels of endotoxins. Mitchell et al. (2015) and Arteaga et al. (2015) similarly found that workers received higher exposure to dust in an aviary system than in either a conventional cage or enriched system. However, in their study endotoxins were higher in the aviary housing system than in the other two systems, and workers experienced more respiratory problems, measured as decreases in pulmonary function, after working in the aviary

Figure 10.6 One of the most serious health hazards for workers in egg production systems is inhalation of airborne contaminants like dust, ammonia, and endotoxin. Exposure to these contaminants can be assessed by asking them to wear a backpack throughout the workday like the one shown, which has air samplers located on the shoulders to measure particulate matter and ammonia exposure. Lung function after a work shift can then be tested using spirometry. For details see Arteaga et al. (2015) and Mitchell et al. (2015).
Source: Photographs courtesy of Diane Mitchell.

than in the other two systems (Fig. 10.6). Larsson et al. (1999) similarly found that airway inflammation was evident in workers after only 3 hours of exposure to poultry dust, and that inflammation tended to be greater for the workers in noncage than cage housing due to the higher dust levels in the former, although in their study endotoxin levels did not differ between the housing systems.

The use of personal protective equipment appears to be an important factor mitigating worker exposures to dust and ammonia, as well as zoonotic hazards (Agunos et al., 2016; Le Bouquin and Huneau-Salaün, 2011). Mitchell et al. (2015) reported that workers who wore respiratory protection (N-95 masks) while working in the barns were less likely to experience reduced lung function after their shifts, although a barrier is that workers may find respirators uncomfortable to wear throughout a work shift (Le Bouquin and Huneau-Salaün, 2011).

10.7 Economics

Ellis and Kempsey (2016) define economic sustainability as being "able to supply a product demanded by customers and consumers at a price that covers costs and delivers a margin to sustain investment." Using this definition, economic sustainability is mainly determined by farmer income, defined as the difference between cost price and farmer revenue price (van Asselt et al., 2015). For egg production, then, assessing economic sustainability involves analysis of the capital investment costs and production costs associated with different housing systems, as well as the purchasing preferences and "willingness to pay" of customers (e.g., retailers, manufacturers, and food service) and consumers of eggs and egg products.

Obviously, these aspects will vary from one country/region to another depending upon many factors (e.g., consumer standard of living, public attitudes and values about egg production, land costs, interest rates, legislation and retailer specifications, labeling and branding, farm subsidies, availability of cheaper imported eggs or alternative protein products), making generalizations difficult. However, studies in the United States and EU have shown that there are consistent production cost differences between systems. Although the magnitude of these differences will vary due to many local factors, conventional cages have the lowest production costs, followed by furnished cages, indoor cage-free systems, outdoor systems, and lastly organic systems (Agra CEAS, 2004; Sumner et al., 2011). These differences are due mainly to feed costs. Feed represents approximately 60% of egg production costs (Matthews and Sumner, 2015), and when hens are provided with more freedom of movement and stocked at lower densities, as they are in noncage systems, they consume more feed per egg produced. Other factors that add to the operating costs in noncage systems are the additional labor needed for management, pullet costs, and housing management costs (Sumner et al., 2011; Fig. 10.7).

Several studies have evaluated the economic sustainability in terms of farmer income of different egg production systems in the Netherlands. Van Asselt et al. (2015) compared furnished cages, barn, free-range, and organic systems, based on expert opinion combined with a modeling approach. They found that furnished cages and organic systems scored higher on economic sustainability than barn and free-range systems. For furnished cages, this effect seems linked to the relatively low production costs (106 Eurocents/kg egg vs 208 Eurocents/kg egg in the organic system), and for the organic system, mainly to the higher farmer revenue price (192 Eurocents/kg egg vs 92 Eurocents/kg egg in the furnished cage). Dekker et al. (2011) compared the economic performance of conventional cages, barn, free-range, and organic systems in a modeling study. They found the highest net farm income for free-range and organic systems. They also found that multi-tiered systems (aviaries) had a higher net farm income than single-tiered systems (floor housing), related to the higher stocking density in the aviary. Similarly, Mollenhorst et al. (2006) found the highest income for aviary systems with free-range access.

Of course, as discussed earlier, farmer revenue price strongly depends on the type of products consumers are asking for. In Western Europe, the market for table eggs from furnished cage systems is rapidly decreasing. The welfare benefits of these cages over banned conventional cages are difficult to communicate and animal welfare nongovernmental organizations and other stakeholders argue that, despite the improvements regarding welfare, a furnished cage is still a cage. This effect may overrule the fact that the furnished cage may be the most cost-efficient system for egg production under current EU legislation, as indicated by van Asselt et al. (2015).

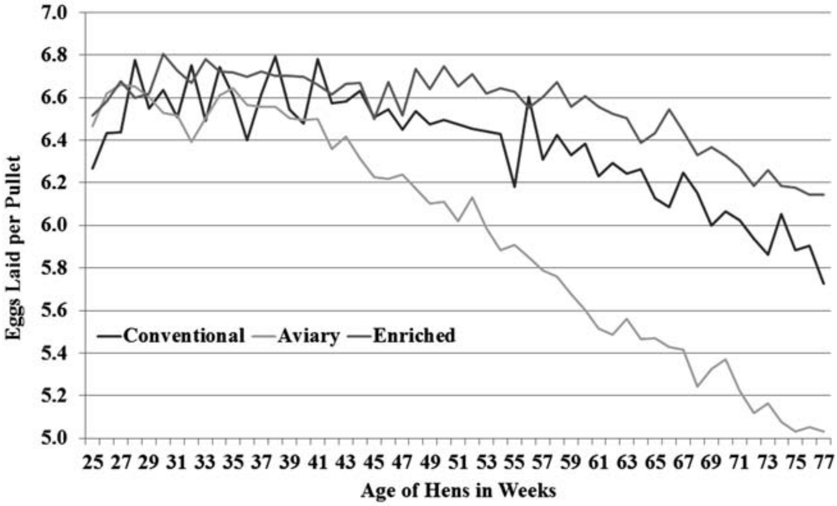

Figure 10.7 Mortality can have a striking effect on production costs. In one study, operating costs were calculated over 2 flock cycles from three housing systems, an aviary, an enriched colony, and conventional cages, on the same farm (Matthews and Sumner, 2015). The graph shows how egg production per pullet placed declined much more steeply in the aviary than in the other two systems. This steeper decline was due to higher mortality in the aviary—by the end of the flock cycle, cumulative mortality had increased to 13.3% in the aviary compared to 5.2% in the enriched colony and 4.8% in the conventional cages. As a result of this higher hen mortality in the aviary, as well as a higher initial cost to purchase pullets for the aviary system (since they had to also be raised in an aviary, which is more expensive than cage rearing), at the end of the flock cycle each aviary hen had cost the producer approximately 50% more than a conventional cage or enriched colony hen.
Source: Graph courtesy of Dan Sumner.

In the United States and several other non-EU countries where cages have not been legally banned (Canada, Australia, and New Zealand) a similar development seems to be taking place, driven mainly by retailers and food service companies. In these countries it appears that conventional cages will mostly be replaced by noncage systems. It is likely that many consumers will be willing to pay for the higher costs of eggs from noncage systems if these are the only eggs available in the market, as the demand for eggs is quite unresponsive to price changes: if the price for eggs increases by 40% it is estimated that this would only result in a 10% drop in consumption in the United States (Sumner et al., 2011). In the EU, many concerns were raised by the egg industry about negative effects of the increased cost of egg production on demand for eggs after the phase-out of conventional cages. Although there was some disruption of egg markets within the first few years after the ban took place, a recent analysis (Windhorst, 2017) showed that egg production in the EU overall has actually increased by nearly 5% from pre-ban levels. There have, however, been regional changes in the distribution of production as well as a decrease in per-capita egg consumption in one of the three countries for which detailed information was analyzed (Poland), likely due to increasing egg prices.

A largely unexplored area is the effect (both in terms of purchasing patterns and the ability to afford purchasing sufficient protein to maintain a nutritionally adequate diet) of even modest increases in egg prices on lower-income consumers, both in developed and developing countries. Eggs are often the cheapest source of animal protein, and the production and consumption of eggs is expected to increase significantly in developing countries during the next few decades. It is anticipated, for example, that global egg production will increase by 22.6 million tonnes between 2010 and 2013, with Asian countries (particularly China) contributing to nearly 65% of that increase (Windhorst, 2016). Economic factors may well play a highly significant role in driving the use of lower-cost cage egg production systems in these countries, which could in turn affect patterns of global trade in egg products (Grethe, 2007).

10.8 Conclusions and implications

As our review indicates, different hen production systems have different risks associated with these five sustainability areas. In many cases, these risks are not absolute—for example, there are usually other factors that have an equal (or greater) impact on risk than housing system per se, such as hen genetics and system management. One exception is the risk of restriction of hen behaviors in cages. In conventional cages in particular, hens are not only unable to nest and perch, but because of space limitations are extremely restricted in their ability to move. Enriched colony cages provide the hens with additional behavioral opportunities, but because of their size still do not allow hens to carry out long-distance movements. On the opposite end of the spectrum, free-range and pasture-based systems by their nature will always require significantly more land use and feed per egg produced than cage systems, with the associated environmental costs.

Returning to the question we asked in the abstract: which egg production systems are sustainable? There have been attempts to answer this question by developing sustainability metrics, essentially creating relative "sustainability scores" for each system. For example, de Boer and Cornelissen (2002) assessed the relative sustainability of conventional cages, deep-litter systems, and aviaries in the Netherlands by consulting with experts and reviewing literature to identify a wide range of key sustainability indicators, which were then converted to scores based on their overall contribution to sustainable development. Their analysis indicated that conventional cages had the least negative impact on sustainability, with aviaries promising but requiring improvement in the areas of economics and farmer welfare. Mollenhorst et al. (2006) carried out a similar analysis in the Netherlands but using data from commercial farms, and stated that that an aviary system with an outdoor run was a good alternative to conventional cages, scoring better on animal welfare and economic sustainability but worse on environmental sustainability.

Analyses like these have to be considered as representing a "point in time," since they rely on current data on impacts such as emissions, system economic performance, egg quality and safety, hen health problems, and so forth, as the basis for the calculation of the sustainability metrics. As we pointed out earlier, however, alternative systems can still be considered in many ways to be in a developmental phase, undergoing innovations in both design and management. As these systems evolve, one would also expect the underlying data to change, particularly if there is an increasing focus on mitigating the problems that have been identified.

Developing effective mitigation strategies will first require a better understanding of the underlying factors affecting the sustainability risks in different hen housing systems. One approach to this process was recently undertaken by the Coalition for Sustainable Egg Supply in the United States, where data on multiple aspects of sustainability were collected on a single farm with three different housing systems over a period of nearly 3 years (Mench et al., 2016). Because the data were collected simultaneously, this project was able to identify synergistic effects among different aspects of sustainability, for example the role that hen dustbathing behavior in the aviary played on dust generation and the subsequent effects of that dust on patterns of air emissions (Shepherd et al., 2015) and worker respiratory health (Arteaga et al., 2015).

Because it was conducted on a single farm, the Coalition for Sustainable Egg Supply study was also limited in that the variations in management and hen genetics that would normally be seen across commercial farms could not be factored into the analyses. However, there have also been recent studies that have used epidemiological-type analyses across farms to identify the system, genetic and/or management risk factors for particular problems, for example vent pecking and cannibalism (Lambton et al., 2015), keel damage and foot problems (Heerkens et al., 2016), and plumage condition (Heerkens et al., 2015).

Once factors affecting risk are identified, strategies can then be developed and targeted toward risk reduction. Lambton et al. (2013) used this approach to assist farmers in reducing feather pecking in their loose-housed flocks by providing them with focused management tools based on the researchers' previous epidemiological analysis of risk factors for feather pecking in such flocks (Lambton et al., 2010). The development of new technologies and methodologies for mitigation will also be important, such as cost-effective litter amendments to reduce ammonia production and emissions (Moore, 2016), alternative feedstuffs or different feed formulations to improve feed efficiency (Leinonen and Kyriazakis, 2016), vaccines for emerging diseases, and alternative parasite control methods that are effective across systems (Mullens and Murillo, Chapter 14), and the application of new genetic technologies to improve animal welfare and production efficiency (e.g., Jensen, 2018; Wang et al., Chapter 15).

One overall initial goal might be to identify and target mitigation of risks that have significant negative impacts in multiple sustainability areas. Hen mortality is one such area, although there are undoubtedly others. Mortality has obvious negative impacts on hen welfare, since most causes of mortality are associated with at least short-term pain and discomfort for the affected hens. Hen mortality also has potential risks for workers, since handling dead hens can place them in direct contact with zoonotic agents. As far as economic sustainability is concerned, mortality increases production costs via increased pullet costs, since the pullets that are purchased by the farmer do not produce eggs throughout the entire laying cycle (Matthews and Sumner, 2015). It also has an environmental impact because of the additional breeding overheads required to produce more chicks to account for later mortality; in their study of nearly 4000 laying flocks, Weeks et al. (2016) estimated by conducting an LCA that reducing breeding overheads by reducing mortality to the levels found in the "best" flocks could lead to a reduction in Greenhouse gas emissions of as much as 25%. Identifying risk factors associated with the common causes of hen mortality and identifying ways to mitigate those factors could therefore lead to improvements in four of the five areas of sustainability (and possibly all five, since some of the conditions that contribute to mortality could lead to stress that reduces the hen's resistance to *Salmonella* colonization during the period of morbidity).

Of course, each system may have some inherent limitations in terms of the extent to which particular risks can be mitigated. And while developing quantitative sustainability "metrics" to rank housing systems would be useful, all attempts to do so will involve making value judgements as to which aspects of sustainability, both within and across the five sustainability areas, are considered more important when they are in conflict (Swanson et al., 2011; Thompson et al., 2011). For example, in addressing hen welfare considerations, when hen health and behavior measures are in conflict which should be weighted more heavily? When environmental impacts and animal welfare are in conflict, which should be weighted more heavily? These kinds of conflicts will ultimately be addressed by stakeholders of egg production via public policy and purchasing patterns. An important priority for the future will therefore be to gain a better understanding of the opinions of stakeholders regarding sustainability issues and how those opinions are influenced by scientific information about the sustainability of egg production.

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Stocking density: Can we judge how much space poultry need?

11

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11.1 Introduction

Stocking density or "crowding" is one of the most sensitive issues in poultry welfare. The initial response of someone seeing commercially housed layers, turkeys, or broiler chickens is often to say that they are so crowded together that their welfare "must" be affected (Busch and Achim, 2015; de Jonge and Hans, 2013; Hall and Sandilands, 2007). This public perception that crowding causes serious welfare problems is reflected in widespread calls for stocking density to be reduced and for producers to give their birds more space (Appleby, 2004; European Union, 2007; RSPCA, 2013). On the other hand, of all the factors that affect commercial production, one of the most influential is how many birds can be kept in a given space, as reducing the numbers of birds in a given space is seen as having an almost inevitable effect on the financial viability of an enterprise (Feddes et al., 2002; Knowles et al., 2008; Petek et al., 2014; Shanawany, 1988; Utnik-Banas et al., 2014). There seems therefore to be an apparent conflict between the welfare interests of the birds that would seem to point to giving each bird more space and the commercial interests of producers that would seem to be in the direction of putting more birds into the same space. Central to resolving this conflict is understanding what the space needs of poultry actually are.

However, despite over 25 years of research (reviewed on broilers, e.g., Arnould and Leterrier, 2007; Bradshaw et al., 2002; Bessei, 2006; Buijs et al., 2009; Bokkers et al., 2011; Estevez, 2007; Robins and Phillips, 2011; for turkeys by Marchewka et al., 2013) there is still no agreement on how much space poultry need and this is reflected in the wide range of regulations, codes, and recommendations currently covering space allowances for poultry across the world. Apart from the obvious difficulties of translating lbs and square feet into kilograms and square meters, the way in which the basic relationship between space and poultry is expressed varies widely. For adult laying birds, it is usually measured as the number of birds per unit area (ft^2 or m^2), and this can be also expressed as a derivative of this—the amount of space each bird has such 0.68, 0.70, 0.75 ft^2/bird. This is often augmented by how much perching space or feeding trough space each bird has, which clearly acknowledges the complexity of what "space" is for poultry and how their needs may vary depending on what they are doing. For rapidly growing birds, however, such as broilers or turkeys, the number of birds in each square foot or square meter has a very different effect depending on their size and age and so a

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measure of bird weight is usually introduced to try and express this, such as the lbs or kg of bird to be found in 1 ft^2 or $1/m^2$.

There is thus a wide diversity of opinion about how to measure "space" as well as how much of it poultry "need" that is apparent in both research findings and legislative requirements and there are two quite different approaches to dealing with this diversity. The first is to argue that the diversity of opinion comes from a lack of research or at least a lack of research of the required standard. The solution here is therefore to undertake more research with agreed methodology with the hope that better science will resolve the differences and enable a consensus to be arrived at. The second approach is to argue that no such consensus is possible because the health and welfare needs of poultry extend so far beyond the physical space available to them that it is positively misleading and actually detrimental to their welfare to attempt to capture their needs in ft^2 or m^2. It might satisfy legislators to be able to have a precise area per bird above which welfare could be deemed to be satisfactory and below which welfare would be regarded as poor, but if there is in fact no such threshold, or even a range of values, the welfare of poultry will not be improved by pretending that there is. The solution here is to resist calls for single numbers that refer to just one aspect of welfare and to see space needs as part of a much wider range of factors that contribute to the well-being of poultry. In support of this latter view is that most scientists working in the field agree that "welfare" or "well-being" is multi-factorial both in the sense that many different measures should be taken to assess it (Fraser et al., 2013) and also in the sense that many different factors (such as age, breed, environment, and social grouping) affect that final assessment. "Space," despite its emphasis by the public and its favored status in the eyes of legislators, should be no exception. Just because it is simple to measure does not mean that it should assume the status of the predominant welfare indicator that takes precedent over the others.

The aim of this chapter is to decide whether it is possible to define the space needs of poultry in a way that is scientifically valid and makes sense in terms of the welfare of the birds themselves or whether the attempt to define space "needs" as if they were separate from other welfare needs is impossible and even damaging to poultry welfare. As both approaches call for a definition of "needs," I will start with a brief discussion of what "needs" might mean in the context of space.

11.2 "Needs" and the assessment of welfare

The term "needs" in the context of animal welfare has a long and somewhat confused history (e.g., Hughes and Duncan, 1981; Thorpe, 1965; Vestergaard, 1982) but is now most usefully divided into two kinds of need (Dawkins, 1983). The first ("ultimate") kind of need is where animals die or become ill as a result of not having something. In this sense, animals need food and water because without them they die. But hens do not die through being kept in cages where they cannot dustbathe, so to argue that hens have a "need" to dustbathe is to use the term in a somewhat different ("proximate") sense, to imply that they are "highly motivated" to dustbathe or that they are frustrated or stressed by being unable to do this behavior. These two meanings of "need" can be summarized by defining good welfare as good health (satisfaction of needs sense 1 above) and the animal having what it wants (satisfaction of needs in sense 2).

This simple dichotomous definition of needs and welfare (Dawkins, 2008) has the advantage that it points directly to the kind of evidence that can show what an animal's needs are. For example, to establish whether an animal "needs" the opportunity to show a certain kind of behavior, we can look for evidence that being able to behave in a particular way either improves its health and/or is something the animal wants to do, as demonstrated by it (for example) learning to peck keys, or push weighted doors, to be given the opportunity to behave in that way. We now have available many different ways of establishing that animals are in a positive emotional state (Boissy et al., 2007; Paul et al., 2005). Animals "having what they want" is a colloquial shorthand for animals being in a positive emotional state.

This dichotomous approach has the further advantage that it encapsulates, but in a simplified and easy to remember way, other more detailed definitions of welfare. Of the 5 Freedoms (FAWC, 2009) for example, two of them (freedom from hunger and thirst and, freedom from injury and disease) refer to physical health, whereas the other three (freedom from discomfort, freedom to perform most normal patterns of behavior, and freedom from fear and distress) refer to positive emotional states expressed as what animals want or what they want to get away from. The 10 welfare principles of the World Organisation for Animal Health (Fraser et al., 2013; OIE, 2012) and the 12 criteria of the Welfare Quality project (Blokhuis et al., 2010) can also be summarized in this way. The 12 Welfare Quality criteria are "absence of prolonged hunger, absence of prolonged thirst, comfort around resting, thermal comfort, ease of movement, absence of injuries, absence of disease, absence of pain induced by management procedures, expression of social behavior, expression of other natural behavior, good human-animal relations and positive emotional state." This list is long and quite difficult to remember but can be summarized as "health" (absence of disease, injury, and pain) and the provision of "food, water and bedding" and the animal having "what it wants" (comfort, ability to move, interactions with others, and positive emotional state).

When it comes to the space needs of poultry, therefore, we can ask two questions: (1) can we define how much physical space poultry need for their physical health? and (2) can we define how much space poultry want? Most research has been done on broiler (meat) chickens but layers, turkeys, and ducks are covered whenever possible.

11.3 Assessment of space needs: Physical health

As Estevez (2007) has pointed out, there are a number of reasons why trying to find a single space allowance that is best for poultry health is extremely difficult.

Chief of these is that different measures of health give different results for the amount of space poultry need for to keep them healthy. We can illustrate this by looking at the results obtained using different health measures.

11.3.1 Mortality

The most basic measure of health is whether animals live or die. Indeed, in its Directive on broiler welfare, the European Union used this to define the maximum stocking density that broiler chickens should experience during their lives as 33 kg/m^2, although this could be increased if certain conditions were met, such as a consistently low level of mortality during 7 flocks (European Union, 2007). However, although this put considerable emphasis on mortality as a key welfare indicator, mortality has been found to vary relatively little with current space allowances and therefore not to be particularly useful for defining space needs (Feddes et al., 2002; Thomas et al., 2004). Buijs et al. (2009) found no effect on mortality in broilers kept in small groups kept between 6 and 56 kg/m^2 and Knierim (2013) found no effect between 18 and 40 kg/m^2. In trials on farms in India, Ghosh et al. (2012) found no effects between 0.8 and 1.2 ft^2/birds and in trials in the United Kingdom and Denmark, Dawkins et al. (2004a) similarly found no effects between 30 and 46 kg/m^2. With laying hens kept in aviaries, Steenfeldt and Nielsen (2015) found that between 6 and 9 hens/m^2, mortality was not affected by stocking density. Lack of the effect on mortality, particularly for short-lived birds such as broiler chickens, is not, however, an adequate measure of health and only a very crude measure of welfare.

11.3.2 Growth rate

A consistent finding is that growth rate in poultry is affected by stocking density—that is, birds grow more slowly at higher densities. This holds for broilers (Benyi et al., 2015; Dawkins et al., 2004a,b; Dozier et al., 2005; Feddes et al., 2002; Petek et al., 2014; Sørensen et al., 2000; Sirri et al., 2007), and is also true for turkeys (Jankowski et al., 2015) and ducks (Xie et al., 2014). On the other hand, it is difficult to define a critical density at which a reduction in growth rate occurs. Cravener et al. (1992) found that when stocking density exceeded 40 kg/m^2, body weight was significantly lower than at 34–38 kg/m^2, whereas Dozier et al. (2006) found a 6% reduction above 35 kg/m^2.

Although high growth rate is sometimes seen as a welfare problem (Cooper and Wrathall, 2010), lowered growth rate seen at higher stocking densities is also seen as a sign of reduced health. Abudabos et al. (2013) showed that at very high stocking densities (45 kg/m^2) broilers showed a marked elevation of body temperatures over broilers kept at 26.5 kg/m^2, suggesting that they were under heat stress. The depression in growth rate may also be affected by changes in gut microbiota at higher stocking densities. Guardia et al. (2011) found that between 12 and 17 birds/m^2, reduced body weight was associated with changes in the bacterial communities found in the crop and caeca.

Interpreting the welfare impact of reduced growth rate in broilers where growth rate itself is regarded as having caused welfare problems (Cooper and Wrathall, 2010) is problematic. The growth rate of broiler breeders is deliberately reduced by feed restriction to prevent health problems caused by overweight (de Jong et al., 2002). As a result of their lower growth rate, the birds are healthier, suffer fewer cardiovascular problems, and have better gaits.

11.3.3 Injury, leg health, and lameness

A number of studies have found that at higher stocking densities, broilers, turkeys, and ducks have greater signs of injury such as more foot pad dermatitis and hock lesions (Bergmann et al., 2013; Buijs et al., 2009; Cravener et al.,1992; Dozier et al., 2005; Hall, 2001; Petek et al., 2014; Sørensen et al., 2000; Ventura et al., 2010; Xie et al., 2014). For example, Knierim (2013) showed higher levels of leg and foot lesions between broilers kept at 18 or 25 kg/m^2 and those kept at 35 or 40 kg/m^2, and Dozier et al. (2006) found that foot pad lesions and skin scratches became more abundant above 30 kg/m^2.

Once again, there is no consensus on how to interpret these results in terms of "space needs," that is, the point or even a range of values, at which the health of the birds is critically affected. One of the major confounding factors is the fact that relatively few studies distinguish between the effects of crowding or stocking density *per se* and the consequences of having a large number of birds in a given space such as a deterioration in air and litter quality. Higher numbers of birds will mean greater litter moisture, increased microbial activity, and increased temperature and ammonia concentration which can give rise to hock burn, dermatitis, and breast blisters (Bessei, 2006). High stocking densities therefore exacerbate the deterioration of air and litter quality but may not themselves be the primary cause of these injuries, as shown by the fact that the low levels of hock burn and pododermatitis can be achieved through better ventilation leading to improved air and litter quality (Dawkins et al., 2004a; Jones et al., 2005). This of course does not mean that stocking density is unimportant to birds but that trying to define space needs without taking into account the quality of their environment could be very misleading and fail to improve the welfare of the birds at all (Estevez, 2007). Stocking density may also affect walking ability or gait through the secondary effects of environmental deterioration (Dawkins et al., 2004a; Dozier et al., 2005; Knowles et al., 2008).

11.3.4 Loss of immunity and susceptibility to disease

"Stress" measured as a rise in glucocorticoids, organ damage, and other physiological change (e.g., Jang et al., 2014; Najali et al., 2015) is difficult to interpret in welfare terms (Rushen, 1991). For example, laying hens allowed access to an area where they could scratch and dustbathe showed higher levels of fecal corticosteroids than hens allowed access to the same space with a wire floor (Dawkins et al., 2004b). But where stress measurements can be related to loss of immunity or greater susceptibility to disease, then connection becomes much clearer.

Tsiouris et al. (2015) challenged (with vaccine or *Clostridium*) broiler chicks in pens at low stocking density (15 birds/m^2) or high stocking density (30 birds/m^2) and showed that the birds at the higher stocking density had higher lesion scores in the gut and liver. However, in this case it was not clear whether this was a space issue or because the litter was worse. Gomes et al. (2014) found that higher stocking density in broilers decreases macrophage activity and antibody titer against Newcastle disease and also increases susceptibility to *Salmonella*. On the other hand, stocking density effects on corticosteroids and heterophil to lymphocyte ratio in broilers are not consistent (Das and Lacin, 2014; Hushmand et al., 2012) and Buijs et al. (2009) found no difference in corticosteroid levels between 6 and 56 kg/m^2.

11.3.5 Conclusions on health measures

The health measures that are easiest to observe and record (mortality, growth rate, leg and foot disorders, lameness) do not give clear cut results in relation to space available and are frequently inconsistent (de Jong et al., 2012; Estevez, 2007). In any case, physical health on its own is not an adequate measure of welfare and additional ways of assessing good welfare are needed.

11.4 Assessment of space needs: Behavior and what the animals want

11.4.1 Choice tests

Faure (1994) conducted an experiment to find out how much space laying hens want by training them to peck at one key to decrease the amount of space available to them and another key to increase the space. Hens were kept in groups of four and each key peck moved a wall by 10 cm in 10 seconds, either moving it back so that the four hens could have a maximum of 6100 cm^2 between them or moving it forward so that they had a minimum of 1600 cm^2 between them. The results were equivocal. Of eight groups of hens, one group learnt to increase the amount of space, four showed no particular preference, and two actually chose to reduce the space, never allowing their cage size to go above 3000 cm^2 (750 cm^2/bird). On the other hand, Buijs et al. (2011b) showed that when given a straight choice, broiler chickens preferred a compartment with a lower stocking density (9.3 or 12.1 birds/m^2) over one with higher density (14.7 birds/m^2). Furthermore, the birds preferred the low stocking density even when they had to cross a barrier that had previously deterred up to 25% of them from gaining access to food when 6 hours food deprived. Unfortunately, not enough studies of spatial preference have been carried out to draw any general conclusions and in any case it is difficult to extrapolate from small experimental pens to commercial poultry houses. As a result, less direct methods potentially more applicable to on-farm analyses have been used to understand how much space birds want.

11.4.2 Spatial distribution

The way birds position themselves with respect to each other—that is, whether they appear to be clustering together or trying to space out as much as possible within a given space—has been used as a way of establishing whether birds want more space, but with contradictory results. Febrer et al. (2006) used the spatial distribution that broiler chickens adopt in commercial broiler houses and found that at stocking densities between 30 and 46 kg/m^2 (14–21 birds/m^2) the birds were more clustered than expected from a random distribution, suggesting that they were choosing to move toward each other even at the highest density and did not find close proximity of other birds aversive. On the other hand, Leone and Estevez (2008) used a different method, the nearest neighbor distance, of much smaller groups of 10–20 broilers in small pens to argue that birds were only attracted to each other at very low stocking densities (2.2–3.4 birds/m^2) and were repelled at stocking densities higher than this. Buijs et al. (2011a) also used nearest neighbor distance to show that, in groups of 20 broilers (at 15 kg/m^2), the birds appeared to be socially aversive in the last 3 weeks of life. But spatial distribution can be difficult to interpret. In one study, adult laying hens observed in small groups were found to be feeding together more often than expected at random but this appeared to be due to common resource use rather than social attraction (Collins et al., 2011). In general, however, studies involving small numbers of birds in small pens provide such a different environment from that of large commercial broiler houses with many thousands of birds that extrapolations from one to the other are difficult, a problem that bedevils the study of stocking density generally.

11.4.3 Area covered

Rather than using the distance that birds choose to put between each other, another method of inferring how much space they need is to measure the area covered by the birds themselves and then use this to calculate the minimum space that is needed by each bird (Ellerbrock and Knierim, 2002; Hurnik and Lewis, 1991; Petherick, 1983), taking into account the fact that different behaviors take up different amounts of space (Bokkers et al., 2011; Dawkins and Hardie, 1989; Mench and Blatchford, 2014). Bokkers et al. (2011) used overhead images of pens of either 8 or 16 broiler chickens (1250 or 625 cm^2/bird) and concluded that at the higher stocking density, some of the behaviors were compressed and that the maximum stocking density should not exceed 16 birds/m^2 (39.4 kg/m^2). Giersberg et al. (2016) took over 3000 overhead photographs of standing and sitting broiler chickens at different ages. By preweighing each bird before placing it in the photo box, they were able to show that there was a strong correlation between bird weight and area covered for both standing and sitting but that even at final target weight (up to 3.2 kg) sitting occupied no more than 77.7% of 1 m. They thus argued that from a purely physical point of view, there is enough room for all birds to sit down at the same time within the space specified in the EU Directive on broiler welfare (2007/43/EC). Using the same method, Spindler et al. (2016) showed that, depending on breed, weight, and age, laying hens occupied an average area of 353–542 cm^2, broiler breeder females between 440 and 537 cm^2, broiler breeder males between 623 and 945 cm^2, male fattening turkeys up to 1808 cm^2, Muscovy drakes up to 873 cm^2, and Peking ducks up to 627 cm^2.

These figures and other calculations of the area covered are, of course, only the minimum space requirement for the behavior to be performed and do not reflect the space the animals themselves prefer to have (see Section 4.1) or whether they want to share that space with other individuals (Section 4.2). In order to translate "area covered" into "space needed," we need additional information about how poultry use space for particular behavior patterns and the effects of different space allowances. Space available at resources such as feeders may be particularly important, since low-ranking individuals may choose to avoid feeding near dominant birds (Grigor et al., 1995) or, if they try to feed, have their behavior interrupted because there is insufficient space around this key resource. For example, when the amount of space available at a feeder was reduced, laying hens were found to spend less time feeding and to desynchronize their feeding times (Thogerson et al., 2009). The amount of space available for perching can also be important, particularly for laying hens, since hens tend to perch simultaneously at night and each hen requires at least 12–15 cm of perch space, depending on breed (Hester, 2014). For laying hens in furnished cages, the number of individual nest boxes available has more effect on aggression than the total amount of space they have (Hunniford et al., 2014) and may also have more effect on the amount of floor-laying in ducks (Makagon and Mench, 2011). Designation of space needs for specific behaviors, such as feeding, perching, and nesting, may turn out to be a more fruitful and evidence-based way of defining space needs than expecting one single measurement to be sufficient on its own.

11.4.4 Behavior showing inferred aversion or negative emotional state

The most widely used method for measuring how much space poultry want is to record the incidence of behaviors that are presumed to indicate that a bird finds the space restriction unpleasant. For example, jostling of other birds, disturbance of resting birds, and birds climbing on top of one another are widely recorded as increasing at higher stocking densities, particularly those above 40 kg/m^2 (Buijs et al., 2011a; Dawkins et al., 2004a; Hall, 2001; Knierim, 2013; Thomas et al., 2011). Where climbing on other birds results in scratching and damage to the body surface (Estevez, 2007; Thomas et al., 2004), the negative effects are clearly related to the physical health of the birds. But even when there is no physical damage, interruption of walking and disturbance of rest can be inferred to have negative effects on birds' welfare (Malleau et al., 2007).

11.5 Complicating factors in the assessment of space needs

11.5.1 Is methodology to blame?

As will be apparent, with the various scientific studies that have been carried out there is still little consensus on the amount of space poultry need for good welfare, and certainly little agreement on a critical threshold or boundary between good and bad welfare (de Jong et al., 2012; Estevez, 2007). Part of the reason for this lack of consensus is undoubtedly methodological: different studies take different measurements and use different methods of analyses. In addition, there is the far larger methodological problem of extrapolating between controlled laboratory studies on small groups of birds and what happens out on commercial farms where thousands of birds are kept together. The differences between these two situations (in group size, air and litter quality, degree of control, for example) potentially have massive effects on how birds respond to changes in stocking density and therefore on the conclusions that are drawn about their needs for space.

However, although methodological difficulties can account for some of the discrepancies in conclusions, it is also necessary to take into account the possibility that there are so many factors affecting the way poultry respond to their environment that the whole concept of "space needs" may have to be questioned as a useful criterion for policy makers. The phrase "it depends" may have to be added so often that it swamps the usefulness of the concept itself. Some of these qualifications (such as whether the study is conducted in the laboratory or on farms or whether the authors have distinguished between the primary effects of stocking density or the secondary consequences on air and litter quality) have already been touched upon. In this section we look at some of the other factors that make giving exact measurements to space needs so hard.

11.5.2 Who is in the space—Social factors

A small empty cage and a larger cage filled with other birds might each give the same physical space but have completely different consequences for an individual bird. Poultry are highly social animals, with changing social behavior as they grow. In young chicks unable to control their body temperature, the close proximity of other birds may be highly attractive, whereas as they grow to maturity and start to form hierarchies this can change. For growing broilers, the size of group in which they are kept (for similar stocking density) seems to have little effect on behavior (Leone et al., 2010), whereas for adult layers, group size seems to be more important than stocking density within the range studied (Pereira et al., 2013). In adult birds, aggressive pecking actually increases with smaller group size (Hughes et al., 1997; Liste et al., 2015; Nicol et al., 1999). This seems to be because in smaller groups, birds encounter the same individuals repeatedly and start to form dominance hierarchies, whereas with large groups they are less likely to do so (Pagel and Dawkins, 1997). "Space" is not empty for poultry. Who is in that space (source of warmth, a known rival, an unknown stranger) will be among many social factors that will affect their need for more or less space, which may change radically as they grow and mature. Males and females may also have quite different responses to changes in stocking density (Zuowei et al., 2011) as do different breeds.

11.5.3 What is in the space—Environmental factors

Just as space needs can be influenced by whether birds want to approach or avoid other birds, it can also be influenced by the physical environment the bird encounters. An area of bare wire floor can be just the same size as an area of litter in which a bird can scratch and dustbathe but have very different consequences for the bird. Recently, attention has been given to the quality of space provided when birds are given barriers, perches, daylight through windows, straw bales, etc. These have had mixed results. Ventura et al. (2010) showed that for layers, barrier perches reduced aggression and disturbances. However, for broilers Baille and O'Connell (2015) found that straw bales did not have much effect and Heckert et al. (2002) showed that perches can actually increase stress through reducing the floor space available.

11.5.4 How space is achieved—Thinning

"Space" is not just a quantity a bird has at a particular time. It also depends on how that space allowance is achieved. A common practice among producers in some countries is "thinning," in which a proportion of a flock is removed as the target stocking density is approached and the reduced number of remaining birds is allowed to grow to target weight (Tuyttens et al., 2014). This enables producers to keep at all times within the specified space limits but to grow a total of more chickens. However, the operation of thinning involves withdrawal of food and the disruption due to the catching team entering the house, which has aroused concern about negative impacts on the welfare of the birds. Here too, focus on one aspect of welfare—space—has not necessarily improved the welfare of the birds themselves.

11.6 Conclusions

The difficulties of defining the space needs of poultry are only partly due to methodological discrepancies between studies and therefore only partly rectifiable by more research. Certainly more on-farm studies, more careful analyses of the direct effects of stocking density and its consequences (such as deteriorating air and litter quality) would help to clarify a number of issues. But even with more research, we would be left with the conclusion that "space" for poultry is far more complex than can be summed up in one single number measured in lbs or kg, or fitted into m^2 or ft^2. Good welfare requires more than just physical space and to place too much emphasis on space as the primary criterion for welfare is potentially to have a damaging effect on the welfare of the birds themselves. First, giving prominence to space allowances (for example in welfare regulations or recommendations) gives the impression that space is paramount and gives producers the message that as long as they are compliant with space requirements, that is all they need to be concerned about. Second, and even more seriously, if stocking density is not the key determinant of welfare that has been claimed, then much effort and expense will go into making changes that will not substantially improve bird welfare. Third, overemphasizing space needs of birds above others leads to practices such as "thinning" that formally fulfill space needs but may be positively bad for welfare. A possible way forward is to be more specific about the space needs that poultry have for performing specific behavior patterns that either have an effect on their health or can be demonstrated to be important to the birds themselves. That way, we can concentrate on ensuring that birds have sufficient space for the behavior that is most important for them. But a good evidence base is essential. Persuading producers to adopt practices that could be costly for them means that we should press first and foremost for changes that will actually improve welfare for the birds themselves.

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Understanding social behavior for better flock management

12

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12.1 Introduction

All poultry species live in groups. These groups can change in structure and composition depending on the season, group size, or availability of resources. Living in groups protects animals from predators and facilitates finding new resources, among other benefits. But living in groups also has negative aspects that can impact on the welfare of poultry, especially in terms of competition for resources reflected in the level of aggressive interactions. Understanding the basic evolutionary principles that caused birds to live together, and their capacity to respond in a dynamic way to changes in the physical and social environment, is crucial to implementing management strategies that reflect the nature of their social behavior, thus allowing optimal welfare. In this chapter, the social behavior of poultry based on the abundant existing literature for laying hens and meat chickens is discussed. The chapter also includes discussion of reproductive behavior and the impact of sexual conflict on bird fertility and welfare.

12.2 Understanding the basic principles of social behavior

All species used in poultry production are social species, although there is variation in their typical group size and composition depending on the species and the season. The typical social organization is based on a more or less rigid hierarchical system that is established though aggressive displays (Buchholz, 1997; Guhl, 1953). In some species the hierarchy is strongly influenced by family ties, as in geese (Jenkins, 1944). In others, like ostriches, loose groups are formed, with the number of birds changing frequently and birds often being solitary (Bertram, 1992). In feral fowl, dominant males hold territories that are shared with females and yearling cocks (Collias and Collias, 1996). However, during the breeding season dominant males monopolize females and drive older competitors (as young males are not considered as real competitors) to the periphery of the territory. Despite the monopoly exercised by the dominant male over females in his territory, females typically mate with more than one male, thus the mating system is described as polygyandrous (Pizzari, 2016). In wild turkeys single-sex groups are more common and

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during mating season males generally establish lekking grounds to which the females are attracted (in Appleby et al., 2004). In ostriches, breeding groups are composed of a male and one or several females. Female ostriches lay eggs in a communal nest that are incubated by the dominant female.

Despite each species' singularities in its social organization as an adaptive response to the social and physical environment where it evolved, there are basic evolutionary principles that are common to these species that made group living greatly advantageous. Social groups confer to their members' competitive advantages and greater survival possibilities, although also have associated costs (Pulliam and Caraco, 1984). Cost−benefit analysis of group living can help explain many of the social phenomena that can be observed even in highly selected poultry such as layers, meat chickens, or turkeys. As discussed in the literature (Beauchamp, 2003; Elgar, 1989; Hamilton, 1971; Roberts, 1996), one of the main benefits of living in groups is the reduced predation risk due to the dilution effect; that is, the more individuals in the group, the lower the probability of any one individual becoming prey. With increasing group size there are more eyes to watch for predators, increasing the probability of successfully detecting them (Krause and Ruxton, 2002; Pulliam and Caraco, 1984). Because less time is needed for effective detection of potential predators, collective surveillance results in more time available to rest and forage (Blumstein et al., 1999; Underwood, 1982), thus increasing the probabilities of survival and reproduction.

It may appear of little relevance to address the role of antipredator strategies in highly selected commercial poultry such as laying hens, meat chickens, or turkeys that are generally maintained in enclosed environments away from predators. However, there are clear signs that modern poultry still maintain strong antipredator behaviors that have been shaped through the evolutionary process and have a powerful influence on their social behavior. Such signs include, for example, the preference for top level perches (Newberry et al., 2001) and for huddling near walls (Newberry and Hall, 1990) or in other well-covered areas (Cornetto and Estevez, 2001; Newberry and Shackleton, 1997; Rodriguez-Aurrekoetxea et al., 2014) to protect themselves from potential predator attacks.

Adjustments in inter-individual distances according to the size of the group and the presence of cover may also be interpreted as evidence of antipredator behavior. Birds in small groups benefit from the protection offered by the presence of cover, allowing them to increase their inter-individual distances to maximize their foraging opportunities (Leone et al., 2007). Behavioral synchronization, which is usually observed during the performance of behaviors that render animals more vulnerable to predation, such as feeding, drinking, dustbathing, or resting, is considered an antipredator strategy. It is clearly observed in poultry (Malleau et al., 2007; Keeling et al., 2003), especially in small groups (Keeling et al., 2017). Because survival in the ancestral species depended so strongly on their success in avoiding predation, and since these are not behaviors selected against in the genetic selection process for performance, it should not be surprising that antipredator behaviors are still evident in modern poultry breeds. Some behaviors may appear in a more relaxed form in the domesticated lines (Eklund and Jensen, 2011), but even the selection for fear of humans over five generations in the junglefowl had only small effects on other fear aspects, sociality, exploration, and foraging behaviors (Agnvall and Jensen, 2016). Thus it is important to consider the relevance of antipredator flock responses in modern poultry because it may lead to problematic behaviors that have a strong impact on the birds' welfare and productive performance. For example, panic reactions, a typical form of antipredator behavior, can cause massive mortalities (a major welfare issue) and indicate the strong need that the birds have to group and seek protection in the event of perceived danger.

Living in social groups provides additional benefits that can help increase animals' fitness and welfare. The benefits for poultry include facilitating thermoregulation in adverse environments by huddling, improving plumage condition through social preening, and reducing fear in novel situations (Newberry et al., 2001). Through social learning and social facilitation animals can discover the location of food sources, stimulate feeding, preening (Hoppitt and Laland, 2008; Hoppitt et al., 2007), and dustbathing in other birds (Duncan et al., 1998). On the other hand, it is also important to consider that behaviors that have a major negative impact on welfare such as feather pecking and cannibalism, are also spread in the population through social learning (Cloutier et al., 2002).

Living in groups implies some costs (see Pulliam and Caraco, 1984), which are most commonly measured in terms of competition for food or access to other valuable resources including mates, which may lower the individual's fitness. In the farm environment food is provided ad libitum and normally it is evenly distributed, thus minimizing competition and permitting coexistence of large groups (Estevez et al., 1997). However, when resources become limited due to unforeseen circumstances, competition for resources will be intense and monopolization of resources by dominants may be favored, triggering aggression and social stress (Hughes et al., 1997). If competition becomes intense individuals in the wild may opt to leave the group, naturally self-regulating group size according to the availability of resources. However, in production animals intense competition due to clumping, reduced accessibility or unavailability of resources (e.g., malfunctioning or lack of proper management feeding equipment) may lead to uneven bird performance, undernutrition of subordinates, and in extreme cases to starvation and death. Likewise, ignoring the birds' needs to group and seek refuge when danger is perceived will lead to panic reactions and unnecessary mortalities, with the consequent welfare implications and economic cost. These costs can be avoided with a better understanding of the biological principles that lead animals to live in groups and the factors that may determine increased competition among group members.

12.3 Social dynamics

12.3.1 Social plasticity: From hierarchy to social tolerance

The size of poultry flocks is a factor that has major implications. From the management standpoint, it is more cost-efficient and practical to maintain one large flock than the same number of birds physically separated into smaller groups. However, if their natural behavior is to establish a social hierarchy with a small number of birds, being in large groups may lead to instability of the social groups and increased aggression with consequent negative impact for the welfare of the birds. Therefore it is important to determine the plasticity of poultry to tolerate variability in group size, specially their capacity to adapt to large groups.

The social organization of the domestic fowl is probably one of the best studied social systems in the animal kingdom since the discovery of the hierarchical structure in this species by Schjelderup-Ebbe (1921; cited in Rajecki, 1988). In the most classical view, the hierarchy or "peck order" is established through aggressive threats and pecks delivered by dominant group members. By doing so, these individuals gain freedom of movement and priority of access to resources (Guhl, 1953). Once the hierarchy is established, a low frequency of aggressive interactions takes place, saving time, energy, and injury potential to all group members as it will be unnecessary to fight over access to resources. But for a hierarchy to be stable, recognition of the group members as individuals (Guhl and Ortman, 1953) and remembering the results of past interactions with each of them (Pagel and Dawkins, 1997) are necessary. Thus a hierarchical system would be feasible in relatively small groups, whereas in larger groups much higher levels of aggressive encounters would be necessary.

In early laying hen studies a reduction in bird performance was observed with increasing group size. Such results were explained as a consequence of the birds' inability to establish a stable hierarchy. It was argued that in these large flocks birds would continually attempt to establish dominance relationships with group members but would fail, resulting in high rates of aggression (Al-Rawi and Craig, 1975; Banks and Allee, 1957; Guhl, 1953). Alternatively, McBride and Foenander (1962) hypothesized that in large groups birds would limit their spatial dispersion to maintain stable subgroups with their own hierarchy, established with known birds within their proximity. They also indicated that strangers to the subgroup would always be attacked. Although the idea that chickens (especially male breeders) establish a dominance hierarchy and maintain territories when housed in large groups is still popular, it is not supported with scientific evidence. Studies conducted in both fast- (Estevez et al., 1997; Newberry and Hall, 1990) and slow-growing meat chickens (Rodriguez-Aurrekoetxea et al., 2014) and male broilers breeders in commercial breeding flocks (Leone and Estevez, 2008a) found no evidence that birds were spatially restricted in their movements, and suggest that the amount of space the birds use is mainly determined by the size of their enclosure (Leone and Estevez, 2008b; Liste et al., 2015; Newberry and Hall, 1990). If there is not restriction in freedom of movement and it is unlikely that birds can establish a stable dominance hierarchy with several thousand birds, are the birds frequently engaging in aggressive interactions?

Contrary to the initial studies, the most recent research shows that meat chickens and laying hens in large groups do not engage often in aggressive interactions (Carmichael et al., 1999; Estevez et al., 1997; Hughes et al., 1997; Nicol et al., 1999). Estevez et al. (1997) proposed the tolerance hypothesis in an attempt to explain why domestic fowl do not engage in constant fighting even though they are unable to establish a dominance hierarchy. The tolerance hypothesis, which is based on cost−benefit analyses, indicates that it is not efficient for birds housed with unlimited food and water to spend time and energy defending resources from other individuals when the number of competitors is high but competition has little effect on the depletion of resources. Thus, under normal farm conditions, with *ad libitum* access to feed and water, birds should be tolerant of their flock mates. Benefits of the tolerance system include freedom of movement unrestricted by aggressive interactions and minimal expenditure of time and energy in aggressive encounters. Several additional studies in which group size in pullets and laying hens was experimentally manipulated found similar results of decreasing aggression with increasing group size (Estevez et al., 2002, 2003; Liste et al., 2015). Even in experimental setups where laying hens were expected to compete for resources and the number of competitors was large they used “scramble” type competition (Estevez et al., 2002), which is a nonaggressive type of competition for resources (Parker, 2000) in which the birds tried to maximize feed intake without engaging in any type of social interaction, sometimes running away to the pen corner to eat it.

With an elegant theoretical model, Pagel and Dawkins (1997) showed that dominance is advantageous only if the probability of meeting the same individuals repeatedly over time is high. Otherwise, the cost of establishing dominance relationships is never recouped. Thus they suggested that the formation of a hierarchy will only be cost effective for a narrow range of (low) group sizes. They also suggested that “resource fights” would be more common in large than in small groups and that overall aggression could, therefore, be similar or higher in large groups despite the absence of dominance-based aggression. According to this model, a low level of aggressive interactions should be expected under conditions that favor the establishment of a stable hierarchical system, as birds would recognize each other’s dominance status and there would be no need to fight over access to resources.

However, in laying hens kept in group sizes varying from 15 to 120, and with different social experience and in situations of competition for resources, Estevez et al. (2002, 2003) found that the large groups generally showed less aggression. This occurred even though the small groups of 15 birds had lived together in stable groups from day 1 of age, therefore meeting all the conditions associated with the development of a stable hierarchical system in which fighting over resources would not be expected. The results obtained in a sequence of experiments in which birds were in a situation of competition for limited resources suggest that the level of aggression was related to the number of competitors and to resource availability. The birds responded to the potential balance between the costs of aggression (in terms of time, energy, and risk of injury) relative to the potential benefits of the resources they could obtain (Estevez et al., 2002). Above a certain level of competition pressure, the birds could obtain a greater payoff by becoming tolerant of other birds and exploiting resources as effectively as possible. Thus the dynamic nature of the aggressive interactions found in this study suggests that cost–benefit principles of group living seem to rule the nature of social behavior in the domestic fowl (and probably other poultry species), despite the artificial environment and the intense genetic selection they have undergone for productive performance. This behavioral plasticity in regulating their social responses is after all to be expected, given that the most important function of behavior is to maximize the adaptive capacity of animals to their physical and social environment. Whether this is a natural or an artificial environment may not matter so much as long as these behaviors are not selected against during the artificial genetic selection process.

12.3.2 Social recognition and the impact of phenotypic appearance

In the previous section we analyzed the dynamic nature of the social behavior of the domestic fowl, which can range from a strict dominance hierarchy to a lax-tolerant system. For a hierarchical system to be effective all individuals must recognize each other (Guhl, 1953; Guhl and Ortman, 1953) so that the dominant can recoup the "cost" invested in aggressive interactions (Candland et al., 1969; Queiroz and Cromberg, 2006) while subordinates can avoid costly aggressive interactions that they are likely to lose. Therefore the individuals' phenotype in the domestic fowl, and probably in other poultry species not yet studied, must play a relevant role to help in the identification of individuals and their social status so that aggressive interactions can be minimized. Phenotypic appearance may also be critical to recognize individuals new to the established hierarchy. In addition, new phenotypes may occur in stable flocks naturally, for example as a consequence of diseases, malnutrition, or injuries due to accidents or cannibalism that may change the appearance of the birds. This change in phenotypic appearance may have consequences for flock social dynamics and therefore for welfare, as these changed birds would be specifically targeted by other birds.

Earlier studies indicate that birds direct aggression not only toward unfamiliar birds (Bradshaw, 1991; Lindberg and Nicol, 1996) but also toward known individuals with experimentally altered feathers or combs (Guhl and Ortman, 1953; Siegel and Hurst, 1962). Difficulty in individual recognition was used as an argument to explain the lower frequency of aggressive interactions observed in large groups (D'Eath and Keeling, 2003). Pagel and Dawkins (1997) indicated that, in the absence of individual recognition in large groups, the social status of each individual is instead replaced by the use of badges of status. For example, a large body or comb size would signal dominance (Cloutier and Newberry, 2000, 2002; Guhl, 1953). Badges of (low) status may be the explanation for the commonly found phenomena in poultry of targeting of small or sick birds, or of targeting pullets that have a delayed onset of lay compared to other hens in the flock at the onset of the production cycle. Such hens, which are usually healthy birds with small combs and yellowish legs and eyes, will often be found perching in the same location day after day and rarely venture to the feeder, because when they do they are aggressively targeted. Phenomena like this are commonly observed in all commercial poultry species. Therefore any internal physiological process or external factors that may cause an alteration in the phenotypic appearance of a bird may have a major impact on its health and welfare, possibly because it alters the bird's badges of status that are used in social dynamics.

Estevez et al. (2003) detected a discrepancy between the rates of aggression given and received in an experiment with pullets. In this study observations were based on focal observations of birds individually marked with a colored dye on the back of their head. The discrepancy found in aggression given and received led the authors to suggest that such results could only be explained if the focal marked birds had become targets of the remaining population because of their distinct feather coloration. The impact of changing phenotypic appearance on the social relationships of domestic fowl was later demonstrated by Dennis et al. (2008) in meat chickens. In their study the frequency of aggressive interactions received by birds carrying a black mark on the back of their heads was substantially higher than for birds that were unaltered, which is an obvious welfare problem. The study also demonstrated an impact on the levels of stress hormones (catecholamine reactivity and norepinephrine) and reduced body weight, thus demonstrating a link between phenotypical appearance, productive performance, and hormonal stress indicators, which could potentially affect birds' resilience to disease vectors. Interestingly, the cost of carrying the black mark was not the same in all the groups tested in Dennis et al. (2008). While the mark had a clear cost in reduced body weight and increased aggression when 20% of the birds in the group were altered, the impact was less evident when 50% were marked, with no impact when all group members carried the mark. Several hypotheses were proposed to explain these results, and, although none of the hypotheses could be totally discarded or supported, the authors favored the social challenge hypothesis. This hypothesis suggests that there is an associated cost for the dominant, in the form of increased social challenges of conspicuous feather coloration that signals dominance (Senar and Camerino, 1998; Senar, 1998; Tibbetts and Dale, 2004). Accordingly, marked birds should attract more social challenges in the form of aggressive interactions relative to unmarked birds in the same flock. This attraction will have been focused on fewer birds when only 20% were marked as compared to 50%, but would have been evenly distributed when all individuals in the group carried the mark.

Similar to the results of Dennis et al. (2008) for meat chickens, research into the implications of phenotypic appearance for the management of pullets and laying hens showed that birds reared in groups of 10 with 30% of the birds artificially altered at 1 day of age had lower body weight at 24 weeks of age (Marín et al., 2014). When looking at their behavior there was no evidence of social challenge to the birds carrying the mark, although when birds with the altered phenotype were in minority they showed higher locomotion and a significant reduction in resting time (Liste et al., 2015), which has a negative impact on their welfare. Although the frequency of aggressive interactions overall was too low to detect whether there was an effect specifically on the frequency of aggressive interactions involving altered birds, there was clear directionality of the aggressive interactions, from unmarked birds toward the marked ones (Campderrich et al., 2017). These studies in meat chickens and layers have helped to determine the impact that changes in phenotypic appearance have on the welfare and productive performance of domestic fowl.

Artificially manipulating the phenotype of a low proportion of adult layers that until then were maintained in stable and phenotypically homogeneous groups led to lower body weight gain and a sudden drop in egg production (Marín et al., 2014). The effects were particularly evident when the mark was added, and were less pronounced when the phenotype was altered by removing the marks from birds that had been kept in homogeneous groups in which all birds had been carrying the mark from day 1 (Fig. 12.1). The reduction in productive performance was probably

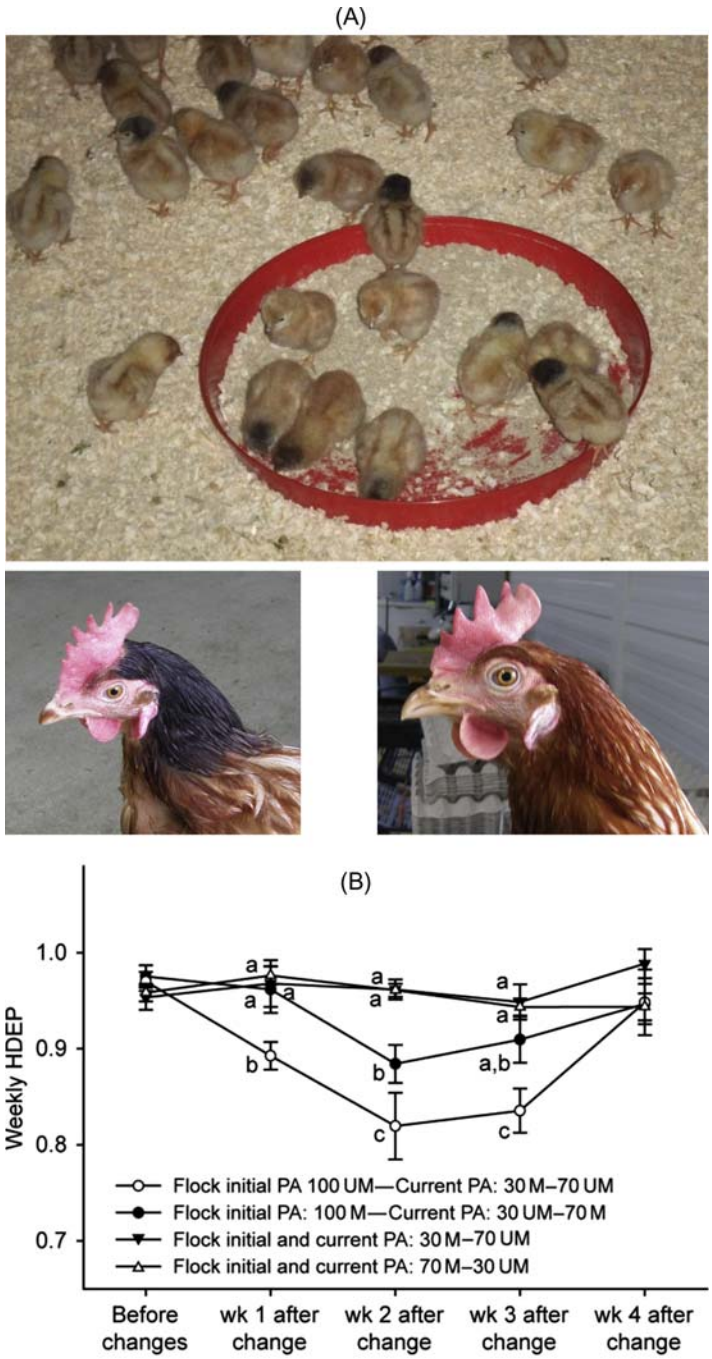

Figure 12.1 (A) Marked and unmarked phenotypes on day 1 and in adulthood. (B) Weekly mean hen-day egg production (HDEP; ± SE) after the phenotypic appearance (PA) of 30% of the group was artificially changed. *M*, marked; *UM*, unmarked; 30, 70, and 100 is 30%, 70%, and 100% of the birds within the group either marked or unmarked. Groups with no common letters (a–c) differ significantly ($P < .05$).
Source: From Marín et al. (2014).

a consequence of social turmoil, as evidenced by a fourfold rise in the frequency of aggressive interactions (Campderrich et al., 2015). Similar to the effects detected for egg production, aggression was higher when the change involved having a mark rather than removing one and was more likely to originate from unaltered individuals toward the new emerging phenotypes (Campderrich et al., 2015, 2017). These results do prove the high plasticity of the social behavior of the domestic fowl that enables them to rapidly react to changes in their social environment, and may provide an explanation for the bullying that some birds experience in commercial poultry production. Phenotypic diversity probably has no major consequences when phenotypic variability is high from early rearing, but it may generate major social disruption if changes occur when the birds are adults. Therefore it is important to start to consider that birds undergoing a change in appearance due to disease, injuries, or other factors may become the recipients or "targets" of a disproportionally high frequency of aggressive interactions.

12.4 Social conflict

12.4.1 The Impact of resource availability and distribution

Assuring adequate access to feed and water is basic to guaranteeing homogeneous health, welfare, and performance in poultry flocks. Poultry diets are adjusted with surgical precision to cover every need for each growth or laying period, and to maximize productive performance while considering additional factors such as environmental impact. Therefore, choosing the adequate diet and providing the birds with the recommended drinking and feeding space may appear to be sufficient to guarantee their welfare and performance. But as indicated previously, living in large social groups has associated costs (Pulliam and Caraco, 1984) such as increased competition for access to feed resources that is relevant in the case of commercial poultry. In social groups of wild chickadees no differences in daily weight gain between dominants and subordinates were observed when all birds were provided with ad libitum access to resources (Pravosudov and Lucas, 2000). And for commercial poultry with access to unlimited resources and little effect of competition on depletion of resources (because feeders are automatically refilled) no major problems are expected (Estevez et al., 1997).

However, we may occasionally encounter malfunctioning feeders that deliver little or no feed, or feeders covered in litter or filled with birds, reducing feed availability or impeding access to it. These events alter the ideal uniformity of feed distribution and may trigger unexpected competition for access to resources. For example, in an experiment with broilers in which feeding efficiency was manipulated by adding increasing proportions of a nonnutritive filler substrate to feeders that contained an identical amount of feed, proportionally higher numbers of birds and levels of aggression (per bird) were observed at the most efficient feeder (Leone and Estevez, 2007; Fig. 12.2).

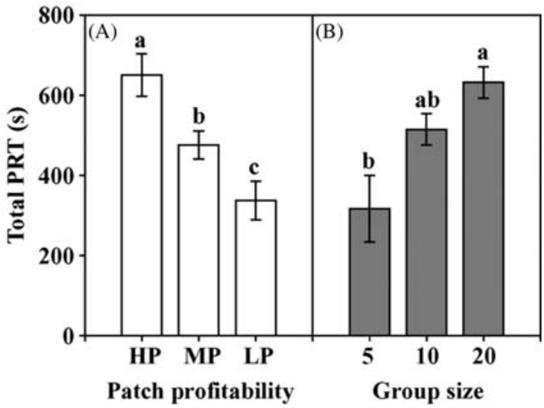

Figure 12.2 Total patch (feeder) residence time (PRT; s) per 30-min testing period (least squares means ± SEM) according to patch profitability (A); high (HP), medium (MP), and low (LP) profitability respectively and by group size (B); GS5, GS10, and GS20, respectively. (a–c) Bars sharing any common letters are not significantly different at $P > .05$ after Tukey's adjustment.
Source: Leone and Estevez (2007).

This capacity to determine the best feeding location is not surprising. Abundant literature on foraging strategies in wild animals has repeatedly shown that animals are able to discriminate and accurately choose feeding patches based on handling time (time needed to manipulate the food to extract nutrients), nutrient quality, and net energy gain (Alonso et al., 1995; Caraco, 1981; Kacelnik and Brunner, 2002; Lewis, 1980; Schaefer et al., 2003). Therefore it should not be surprising that the highest level of competition in broilers, which have been selected to grow efficiently, was observed at the feeder that allowed the fastest, most efficient, feed intake. From a practical standpoint, this would suggest, for example, that if feeders are not maintained free from litter increased competition will take place at the cleaner feeders that permit a higher feed intake. In other circumstances competition for resources might be subtle and pass undetected until a reduction in productive performance and/or disparity in body condition is detected. Even if feeders are maintained in perfect order, competition may appear due to unusual environmental conditions, for example as a consequence of unusually high temperatures that make hens avoid feeding during the day to reduce heat production. When temperature declines an unusually high number of birds may visit the feeders, creating a highly competitive situation in which less competitive birds may have difficulties acquiring enough feed. If the situation is sustained over the course of several days it will result in a significant reduction in performance and large body condition differences.

It is well known that poultry can regulate their nutrient needs and have a balanced diet even when the ingredients are provided separately, known as free choice feeding (see Singh et al., 2014). Free choice feeding has some advantages over standard feeding practices especially in production systems that provide birds with additional behavioral opportunities, like free range systems, in which birds may have different nutritional requirements according to their level of activity. This feeding practice permits producers to use locally grown grains, an advantage that may improve consumer acceptance of the production system. However, free choice feeding is not easy to implement in practice. Competition for the most preferred ingredients is difficult to control and may potentially lead to a high variability in health status and performance of the birds. Perhaps difficulty in controlling competition for resources is one of the reasons why the results of free choice feeding studies are contradictory (Singh et al., 2014).

Not only the amount of a certain resource, but also its availability and distribution within the environment, will affect the frequency and intensity of aggressive interactions, as demonstrated for layers (Estevez et al., 2002). Thus knowing how resource availability and distribution may affect the level of competition among birds in the flock is essential for adjusting management and maximizing flock homogeneity.

12.4.2 Understanding the factors triggering aggression

The size of groups in natural populations is self-regulated. In fact, group size can be considered a by-product of environmental conditions, as animals will join or leave the group depending on the availability and quality of resources in the environment and on the level of competition. On the contrary, in farm animals group size is established by the farm manger and depends on the dimensions of the enclosure and the density of animals per unit of space. Changes in group size and density may occur without really implementing adjustments in the environment to accommodate variations in the number of birds. Because group size and density are two of the major factors that shape the relationship between costs and benefits of living in groups, and indeed affect the fitness of the group members, the analysis of the social changes that occur as the number of animals increase has major relevance for welfare and production.

It would be expected that as the number of individuals in the group (group size) or per unit of space (density) increases, there will be more social instability (based on the hierarchy formation hypothesis) and higher levels of competition, reflected in increased aggressive interactions. Although most available studies confound the effects of density with group size, or alternatively with those of enclosure size, scientific evidence indicates that the frequency of aggressive interactions in poultry actually declines with increased density and group size (Carmichael et al., 1999; Estevez et al., 1997, 2003; Hughes et al., 1997; Liste et al., 2015; Nicol et al., 1999). This is, of course, under conditions where available resources are provided *ad libitum*. If resources are limited, or are not evenly distributed, bird responses will be very different.

Interestingly, most aggressive interactions seem to take place in open areas (Pettit-Riley et al., 2002; Ventura et al., 2012), where inter-individual distances are normally larger and birds are not in the proximity of resources to be defended. Rodriguez-Aurrekoetxea and Estevez (2014) analyzed the behavior, orientation, and inter-individual distances among the giver and receiver of aggressive interactions immediately prior to the onset of the encounter in a commercial layer house. Identical information was collected on the two individuals closest to the giver and to the receiver of the interaction. The authors found that aggressive interactions emerged as a combination of proximity (around 30 cm), orientation, and activity (or "attitude") of the birds, and not by simple invasion of an individual's personal space. The requirement of these three elements to act simultaneously to instigate an aggressive interaction would explain the recurrent findings of reduced frequency of aggressive interactions when space availability diminishes. Under severely restricted spatial availability where lower levels of aggressive interactions are observed, the frequency of active behaviors such as walking or running is lower because of the presence of other birds that act as barriers to movement (Estevez et al., 1997; Newberry and Hall, 1990). This situation would naturally limit the chance that birds will confront each other while active, thus resulting in reduced aggressive interactions (Rodriguez-Aurrekoetxea and Estevez, 2014). Similar reasoning would explain the beneficial effects of reducing the frequency of aggressive interactions by the presence of cover panels in meat chickens (Cornetto et al., 2002; Fig. 12.3). The presence of panels or other similar type of structures that increase spatial complexity reduces the chances of birds encountering one another when active, thus minimizing the conditions leading to an aggressive encounter.

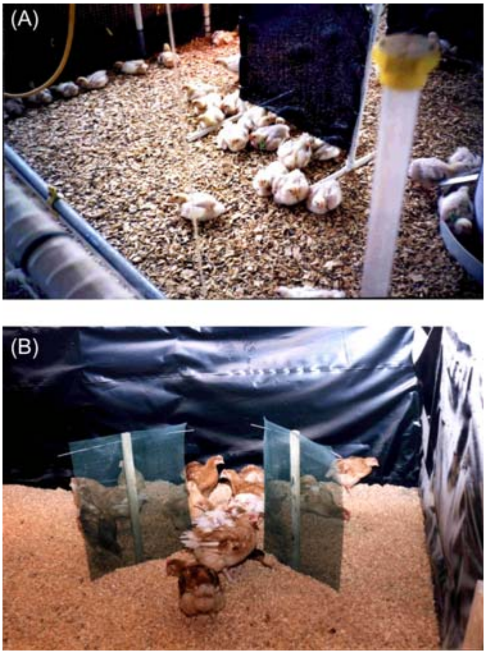

Figure 12.3 Fast- (left) and slow-growing (right) meat chickens using two different types of cover panels in two experimental setups.
Source: Photos by I. Estevez for fast growing and R.C. Newberry for slow-growing birds.

12.5 Social behavior and reproduction

12.5.1 Mating systems in the domestic fowl

Traditionally, the fertility of breeding stock has been perceived to be largely dependent on genetics and nutrition. However, a bird's fertility is largely influenced by its interactions with other group members and by complex sperm competition mechanisms (Birkhead et al., 1999). This strong social component of fertility explains why genetic selection has little effect on improving fertility in the domestic fowl (Pizzari, 2016). As indicated previously, one of the benefits of dominance is priority for access to resources, which includes mates that would assure high reproductive success (fitness). Thus reproductive behavior should be considered as a specific aspect of social behavior.

In the wild, adult males will defend a harem of females from the incursions of multiple satellite males. Despite the attempts of the male to monopolize the females (harem polygyny), females will mate with more than one male (polyandry) (Pizzari, 2016). This reproductive system leads to similar fertility among females, but to high variations in male reproductive success that will depend on the number of the male's partners and their fecundity. Dominant males will have high fertility while subordinates will sire a small proportion of offspring. Thus, evolutionary history has placed a strong pressure on the males to compete for access to females, and especially to the most fecund females, in order to maximize their reproductive success (Pizzari, 2016).

Although it may appear that genetic selection has modulated the intensity of sexual competition, there is evidence to suggest that the mating system in the domestic fowl does not differ so much from the wild junglefowl. For example, higher fertility of dominant males was observed by Jones and Mench (1991) and experimental work with broiler breeders has shown that male domestic fowl modulate the frequency of mating according to the level of competition for access to females (Bilcik and Estevez, 2005). In the studies conducted by Bilcik et al. (2005) most experimental groups with three males and between 10 and 12 females showed an almost linear hierarchy in male mating frequency. However, mating success was not correlated with paternity rate due to morphological aspects that interfere with reproductive success in heavy strains of domestic fowl (McGary et al., 2003a). Mating takes place mainly late in the evening (peaking between 7 and 9 pm) (Bilcik and Estevez, 2005), a strategy which has been shown to maximize the chances of egg fertilization in a free-ranging population of red junglefowl (Pizzari and Birkhead, 2001). As for the red junglefowl, most domestic fowl females (around 72%) in the study by Bilcik et al. (2005) produced chicks from at least two males of the three available in the flock. However, in commercial practice the highly competitive male behavior for matings that it is observed in wild populations (Pizzari, 2016) can create important welfare problems and a significant reduction in reproductive performance of the flock due to female injury and mortalities that at times can be severe (Estevez, 2009).

12.5.2 Managing sexual conflict

It has been argued that the progressive reduction in fertility and occurrence of female injuries (Fig. 12.4) and mortalities in broiler breeder flocks may be due to changes in mating behavior (Cheng et al., 1985) and reduced frequency of courtship behavior, together with a high frequency of forced mating and aggression (Millman and Duncan, 2000a,b). It has been speculated that this behaviour is a secondary consequence of the genetic selection for high growth rate and meat yield. McGary et al. (2003b), on the other hand, compared two commercial genetic lines with different levels of fertility, and found no differences in the frequency of aggressive interactions toward females. In fact, aggression toward females was extremely low in both genetic lines. Although the frequency of aggressive interactions was not directly studied in Bilcik and Estevez (2005), to determine the impact of male−male competition, three males were placed in groups of 10 females, a male density three times higher than the normal male density used under commercial conditions. No female damage or mortality was observed during the course of the study (personal observation).

Pizzari (2016) indicates that, when multiple reproductive opportunities are available to at least one of the individuals and reproductive investment is costly, this leads to sexual conflict. The differing interests between the sexes are often irreconcilable. In this situation the pursuit of males' fitness will lead to negative effects on female partners. The implications of the evolutionary basis of reproductive behavior in domestic fowl are that if females are not easily available, males will fiercely compete for the few available partners. In an attempt by the males to optimize their reproductive success, available females will be forced to mate repeatedly with several males, a process in which females may be severely injured and which can occasionally produce high female mortalities. Spatial segregation of males and females on the litter and slatted areas of the house is a warning sign. This situation may occur as consequence of the asynchrony in the sexual maturity of males and

Figure 12.4 Example of injured broiler breeder female under commercial conditions due to repeated forced mating.
Source: Photo by I. Estevez.

Figure 12.5 Broiler breeder males and females using protective cover in a commercial flock. *Source*: Photo by I. Estevez.

females, with males in commercial flocks usually maturing before the females. Females will seek refuge in the slatted area, while males force copulations on the few females that venture to the littered area. A common practice to control this problem is to reduce the male to female ratio in the flock. However, this practice will have little to no effect because while spatial segregation lasts there will always be a much higher male to female ratio in the littered area. An effective strategy with demonstrated success is to enrich the litter area with cover panels (Estevez, 1999). The panels are effective in attracting and maintaining a sufficiently high number of females in the littered area (Fig. 12.5), thus drastically reducing the intensity of male competition for matings even while maintaining the number of males (Estevez, 1999). In addition, the visual protection offered by the panels (or other devices that may serve to a similar purpose) reduces male interference during copulations and offers protection to females from excessive matings, both of which may be associated with higher flock fertility (Leone and Estevez, 2008a).

12.6 Conclusions and implications

The species used in poultry production are social species with very complex and dynamic social behaviors. To assure the welfare of poultry it is essential to understand the nature of the different forces that bring the birds together and the factors that may trigger competition for resources, including mates. Even though poultry have been intensively selected for production or reproductive traits, their natural behaviors, and especially those behaviors that had a high impact on the survival and reproductive success of their ancestors, are still very obvious in commercial poultry flocks. Sometimes these behaviors can cause an important welfare problem that often also has a performance and economic impact for the farmer. Knowing the evolutionary origin of the problematic behaviors can give us clues to implement the necessary management strategies to minimize or to control the impact of such behaviors. For example, the risk of panic attacks, which can cause massive mortalities on commercial poultry farms (a major welfare as well as economic problem), can be reduced if we understand that the natural response of poultry is to group (one important benefit of social behavior) and seek refuge. Thus providing small barriers perpendicular to the house length will serve as refuge for grouped birds, preventing a sudden massive migration toward the far end of the house.

On the other hand, in recent years research has provided evidence that the dynamic and plastic nature of their social behavior facilitates adaptation of the birds to variations in the physical and social environment. Perhaps too much attention was given to determining the optimal group size for commercial poultry production, while more recent research shows that in fact, the domestic fowl have a great adaptive capacity to adjust their social behavior to their environment. As evidenced by recent research, changes in the appearance of the birds can cause those birds to be recipients of unusually high aggression, bullied in other words, even when they are in small groups where a hierarchical structure should be expected. Having a small area in which to put bullied birds that is away from the flock will often permit them to recover and be reintroduced into the flock once their normal appearance is regained. It is also important to consider that the major cost of living in groups is competition for resources. Thus, even if the right number of feeders and drinkers are placed in the house they may not be available to all birds, which is a situation that may trigger increased competition. This could happen when there are broken or dirty feeders, or unusually high temperatures that may increase competition at the feeders, resulting in increased variability in body condition.

The management of breeding stock is particularly complex and needs far more attention and research emphasis. Besides the consequences of their already complex social behavior, it is necessary to understand the potential impact of sexual conflict. Although there is little research on commercial flocks of breeding poultry, the available studies suggest that, similar to the red junglefowl, sexual conflict originates from the irreconcilable interest between males and females regarding their reproductive success, and that this conflict can be a source of female mortality if breeding flocks are not correctly managed. The negative impact of forced matings can be reduced by assuring synchrony between males and females in reaching sexual maturity and thus preventing spatial segregation of males and females. The implementation of environmental enrichment strategies, such as adding cover, helps to maintain a high number of females in the litter area, reducing the incidence of forced mating and improving flock reproductive performance.

These examples illustrate the relevance of understanding the dynamic, plastic, and complex nature of the social behavior of poultry and how relevant it is to not only to assure optimal bird welfare but also to address some of the most important problems that hinder bird performance.

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Welfare issues in turkey production

13

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13.1 Introduction

Wild turkeys were domesticated in Mexico over 2000 years ago (Buss, 1989; Crawford, 1992). Turkeys were initially selectively bred for traits such as feather color and pattern, but were later bred for meat production, body conformation, and white feathering, resulting in most commercial domestic turkeys being white feathered by the 1960s (Appleby et al., 2004). In addition to the changes in selective breeding, there were changes in management and housing such that most turkeys have been housed indoors in controlled environments since the 1960s. Intensive housing and selective breeding has made it possible to produce a 21 kg male turkey at 19 weeks of age for today's market, whereas the average turkey in the 1960s weighed 8 kg at slaughter (United States Department of Agriculture National Agricultural Statistics Service, 2016). Another consequence of selective breeding for meat production and body conformation is that modern commercial turkeys, such as those seen in Fig. 13.1, are unable to mate naturally. Consequently, the use of artificial insemination is required, making commercial turkey production different from any other type of poultry production.

With increased consumer interest in animal welfare, the number of animal welfare certification programs has also increased, and therefore, the number of turkeys produced for niche markets. There is a wide selection available for consumers of turkey meat. In the United States for example, consumers can choose among free range, American Humane Certified (2013), Animal Welfare Approved (2015), Certified Humane (Humane Farm Animal Care, 2014), Global Animal Partnership (2015), and United States Department of Agriculture (USDA) certified organic turkeys. In many cases, these certification programs are aimed at providing higher welfare standards for turkeys. For instance, a requirement for organically raised and free range turkeys is that the turkeys are provided with outdoor access (however, this does not necessarily mean the turkeys have continuous, permanent outdoor access). Turkeys produced under other certification programs may or may not have outdoor access, depending on the requirements for that program. Furthermore, providing outdoor access does not necessarily lead to improved welfare because there are many factors, such as management, that influence turkey welfare. There are other differences among certification programs, such as the amount of space the turkeys have and what weight the turkeys reach before they are slaughtered. Based on the increase in animal welfare certifications alone, turkey welfare has come a long

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Figure 13.1 Commercial male turkeys.
Source: Image courtesy of Butterball.

way since the first commercially produced turkeys. The number of scientific investigations into turkey welfare issues is still limited, but has been increasing in recent years.

This chapter reviews the major welfare issues of domestic turkeys, including leg weakness, lameness, and injurious pecking, which affect turkeys at all stages (brooding and grow-out) and in all types of production systems (meat turkeys and turkey breeders). Other welfare issues that are reviewed include fear and stress, catching and transportation, and welfare issues of turkeys raised for breeding. Catching and transportation for moving turkeys between production facilities or for moving turkey breeders are major stressors and have the potential to have lasting effects on turkey welfare throughout the production cycle. For turkey breeder hens and toms, which are in production much longer than turkeys slaughtered for meat, feed restriction is a major welfare issue, in addition to leg weakness (toms) and injurious pecking (hens and toms).

13.2 Fear and stress

Animal welfare is threatened when an animal experiences stress, which Moberg (1993) defines as the biological response to a perceived threat to homeostasis. Turkeys experience a number of potentially stressful events throughout the production cycle, including handling, catching, transportation, noises, and unpredictable events, as well as social stressors. Many of these events also elicit fear, which is the reaction to a perceived threat or danger (Forkman et al., 2007). Physiologically, an animal experiences stress concurrent with fear (Armario et al., 2012). Therefore, it is useful to discuss stress and fear together.

Fear is considered to be a state of suffering (Jones, 1996) and is so important for animal welfare that freedom from fear (and distress) is one of the Five Freedoms. Fear responses are undesirable in commercial confinement production systems because animals may injure themselves or others. Although domestication has resulted in a general decrease in fearfulness, turkeys continue to exhibit strong fear responses. Reducing fear responses, whether through selective breeding or environmental and management changes, will improve turkey welfare, but first, a better understanding of fear responses of turkeys is needed.

13.2.1 Individual differences in fear responses

Turkeys' responses to various situations that elicit fear (quantified by tonic immobility, open field test, and human approach test) have been shown to be consistent over time, with the exception of their responses to novel objects (Erasmus and Swanson, 2014). Individual turkeys are consistent in some fear responses, but there are distinct differences among individuals in their fear responses. For example, turkeys differ in their responses in an open field test, which tests animals' responses to novel environments, with some turkeys being more active and others remaining stationary during the test (Erasmus et al., 2015). Turkeys also differ in their responses to novel feed types (feed neophobia): some turkeys take longer to transition to a new feed type, whereas other turkeys are more exploratory (Lecuelle et al., 2010). Individual differences in fear-related behavior are important from an animal welfare standpoint because differences in fear responses are associated with differences in how animals respond to stress and disease challenges. For example, Huff et al. (2003) tested turkeys in a T maze, which involves elements of novelty and isolation and tests how long turkeys take to reinstate contact with conspecifics (social reinstatement motivation). Turkeys that were classified as FAST in the T maze (took 20 seconds or less to move from the center of a maze back to hatch mates) differed from turkeys classified as SLOW (took longer than 60 seconds) in response to challenge with dexamethasone, a synthetic glucocorticoid that induces a physiological stress response, and *Escherichia coli*. FAST turkeys had lower body weights and increased susceptibility to the dexamethasone-*E. coli* challenge compared to SLOW turkeys (Huff et al., 2003).

13.2.2 Early experience

In addition to individual differences, early experience is another factor that can influence how animals respond to challenges in their environment. Early experience with different environmental factors can have lasting effects on turkey welfare and productivity and it is possible to reduce turkeys' fear and stress responses through early manipulations. For example, Lecuelle et al. (2011a,b) examined whether early experience with different feed colors and feed types reduced feed neophobia during feed transitions. Feed neophobia was reduced in turkeys that were exposed to several different colors of feed when the feed offered before the feed transition contrasted markedly with the novel feed (Lecuelle et al., 2011a). However, previous experience with either light or dark feed did not reduce feed neophobia when transitioning from crumbles to pellets, whereas feed neophobia was reduced in turkeys transitioning from green crumbles to green pellets (Lecuelle et al., 2011b).

13.2.3 Genetic differences in fear responses

Not only do fear responses vary among individuals, but there are differences between genetic lines of turkeys as well. In order to examine the relationship between genetic background and various production indices, several genetic lines of turkeys were developed, including three randombred control lines (RBC1 line, RBC2 line, and RBC3 line), a genetic line selected for increased egg production (E line), a genetic line selected for increased body weight (F line), and turkeys from the F line that had been further selected for increased shank width (FL line). For further details about the respective genetic lines, see McCartney (1964), McCartney et al. (1968), Nestor (1977, 1984), Nestor et al. (1985), and Nestor et al. (2000). Fear responses differed among the genetic lines at 20 weeks of age: F line turkeys required fewer inductions to induce tonic immobility and had longer durations of tonic immobility (indicating greater levels of fear) compared to RBC2 and FL line turkeys, possibly suggesting that the selection for larger body weight is associated with greater levels of fearfulness (Noble et al., 1996a). However, turkeys of larger body weights may have more difficulty in moving and may have other biological and physiological differences compared to smaller bodied turkeys, which may confound interpretations of fear test results. Compared to a modern commercial line of turkeys and F line turkeys, turkeys of the E line were less active in a T maze test at

2 days of age and an open field test at 8 days of age, which may indicate reduced social reinstatement motivation in these turkeys (Huff et al., 2007).

Differences among modern commercial turkeys and the RBC2 line, seen in Fig. 13.2, have also been examined. When tested in an open field test, turkeys of the commercial line formed three distinct clusters based on their responses in the open field test, whereas turkeys of the RBC2 line formed two clusters (Erasmus et al., 2015; Fig. 13.3), indicating a possible genetic difference in open field responses. There is some evidence that that fear responses differ among modern commercial lines of turkeys as well. Noble et al. (1996b) compared two (undisclosed) commercial lines and reported that the duration of tonic immobility, but not the number of inductions needed to induce tonic immobility, differed among the two genetic lines. Anecdotally, some of today's commercial turkey lines are

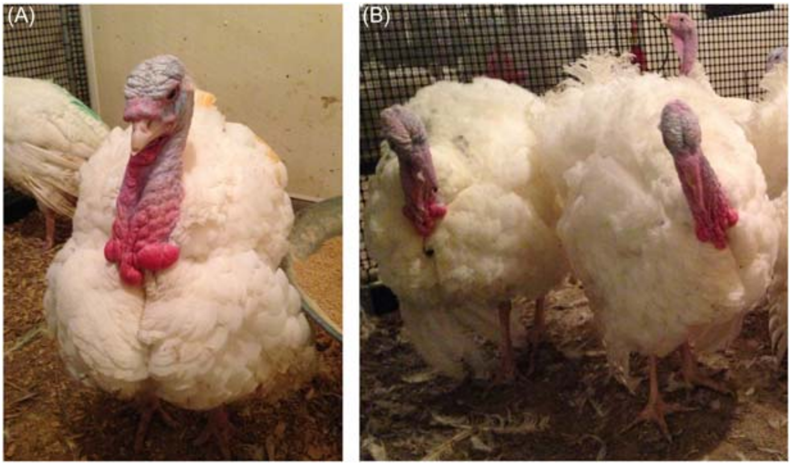

Figure 13.2 (A) Commercial male turkey (Hybrid Converter genetic line) and (B) randombred male turkeys (RBC2 genetic line).

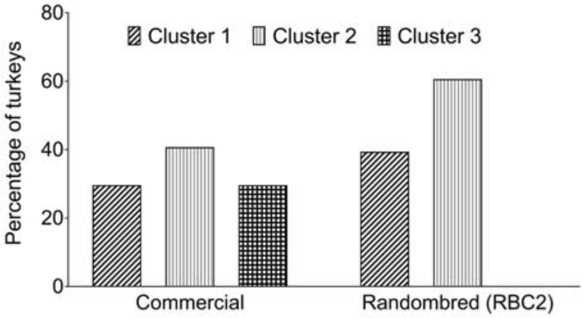

Figure 13.3 Percentage of commercial (Hybrid Converter) and randombred (RBC2) turkeys that were in each cluster based on their behavior in an open field test. Turkeys in cluster 1 were more active and vocalized more compared to turkeys in the other clusters (Erasmus et al., 2015).

reported as being more “flighty” than others, but limited published scientific evidence is available. In order to continue to improve turkey welfare, more emphasis will need to be placed on the possibility of reducing fear responses through selective breeding.

13.2.4 Transportation and related stressors

13.2.4.1 Catching, crating, and transportation

Catching, crating, and transportation represent major stressors in the lives of turkeys. Turkeys are transported several times throughout their lives, such as from the hatchery to the brooder barn, from the brooder barn to the grower barn, and to slaughter. Therefore, transportation and the activities surrounding transportation have the potential to impact turkey welfare at all stages of production. Transportation is associated with a number of stressors that may impact turkey welfare, including fasting and water restriction prior to catching and loading, the capture and handling of animals, mixing of unfamiliar animals, an unfamiliar environment, and conditions associated with transportation itself, such as noise, vibrations, temperature changes, and sudden stops and starts. Other welfare concerns associated with transportation include injuries and broken bones.

Little information exists in terms of the numbers of turkeys that are adversely affected by transportation, but one study (Petracci et al., 2006) reported that the average percentage of turkeys that were dead on arrival (DOA) at slaughter plants in Italy was 0.38% (varying from 0.04% to 1.23%), with DOAs being higher in the summer (0.52%) than in the fall (0.29%), winter (0.29%), or spring (0.32%). There are many possible causes of mortality during transportation, including (1) factors associated with the animals themselves such as health status, age, and size; (2) management factors, such as the manner in which birds are loaded onto the vehicle and loading density; (3) factors associated with transportation, such as the microclimate within the vehicle, length of time on the vehicle, and distance traveled; and (4) lairage (reviewed in Schwartzkopf-Genswein et al., 2012). Furthermore, turkeys are susceptible to heat stress which is a concern on transport vehicles when the density of animals is high and ventilation is not uniform throughout the vehicle.

13.2.4.2 Load-out

Prior to being transported, turkeys are caught, handled, and crated before being loaded onto trucks, collectively referred to as load-out. The period of load-out is especially important from a welfare perspective because of the risk of broken bones and injuries. Turkeys experience more stress from catching and loading than from being transported (Ritz et al., 2005; Voslarova et al., 2011; Vosmerova et al., 2010; reviewed in Schwartzkopf-Genswein et al., 2012). Moreover, the conditions during catching and loading have sustained effects on turkey welfare during the remainder of their journey to slaughter (Whiting et al., 2007).

13.2.4.3 Loading systems

The adverse impacts of catching and loading on turkey welfare depend on the type of loading system that is used. Prescott et al. (2000) compared different systems for loading turkeys prior to slaughter, and reported differences depending on whether turkeys were loaded manually by workers or mechanically. The system that was associated with the fewest indicators of injury (impacted heads, caught tails, fresh blood on the wings after unloading) and carcass bruising after slaughter was a mechanical system whereby turkeys were herded into the system without being physically caught by workers. Prescott et al. (2000) further determined that the design of the system into which turkeys are loaded is also important. Specifically, they found that the incidences of impacted heads were greater in systems where turkeys were placed head-first into modules compared to a system that required turkeys to be lifted into drawers. However, turkeys struggled more, and more turkeys had blood on their wings when lifted into drawers. Heart rates differed among systems as well. Overall, mechanical loading systems appear to be more beneficial for bird welfare; this has been reported for other poultry species as well (reviewed in Kettlewell and Mitchell, 1994; Terlouw et al., 2008). Another loading method that is used, but that has not been scientifically examined, is where workers move turkeys toward a conveyor with the use of flags or other devices that do not require the birds to be physically handled. The conveyor moves the turkeys to a waiting vehicle, where an operator may need to physically place birds in crates on the vehicle.

13.2.4.4 Crate height and transit time

After being loaded into crates and onto the transport vehicle, turkeys may be confined in crates for several hours. Crate height and crate design can affect the types of injuries turkeys sustain during transport (Prescott et al., 2000 in Wichman et al., 2012). Moreover, crate height can affect the behavior of turkeys during transport, but there is a trade-off between the ability to perform certain behaviors and injuries sustained in the crate. Wichman et al. (2010) found that the behavior (preening and standing) and movement (ability to turn around) of turkeys was greatly restricted in crates 40 cm in height compared to crates 55 or 90 cm in height. However, increased crate height during transportation to slaughter is not necessarily better in terms of animal welfare because there was a higher number of scratches on carcasses of turkeys transported in crates 55 cm in height (Wichman et al., 2012).

In addition to crate height, turkeys' welfare is influenced by the amount of time that they are in transit. Published research directly examining turkey welfare during transit is limited, but carcass scratches and bruising can be used as indirect indicators of turkey welfare before slaughter. McEwen and Barbut (1992) reported that the incidence of bruised drums was higher on carcasses from turkeys that were kept on trucks for longer periods of time, perhaps because the amount of time to sustain injuries was longer (McEwen and Barbut, 1992). Examining carcass scratches and bruises is one way to assess welfare, but the availability of new technologies makes it possible to develop other methods for assessing turkey welfare during transit. Marques et al. (2016) examined gene expression of acute phase proteins as an indicator of turkey welfare following transportation because acute phase proteins are involved in inflammation, disease, and other types of stress (Marques et al., 2016). The gene expression of acute phase proteins in the liver was much higher in turkey hens that had been transported for 2 hours compared to hens that had not been transported, adding further evidence that transportation presents a significant stressor for turkeys (Marques et al., 2016).

13.2.4.5 Stress and disease susceptibility

Stress has direct, negative consequences for turkey welfare, and further affects turkey welfare through detrimental effects on the immune response, leading to increased susceptibility to bacterial infections (Huff et al., 2007). However, the welfare consequences of stress differ between male and female turkeys and between larger bodied and smaller bodied turkeys.

Huff and colleagues have conducted numerous studies investigating the association between stress and disease susceptibility in turkeys (e.g., Huff et al., 2000, 2001a,b, 2003, 2005, 2007, 2008, 2009, 2010, 2011, 2013, 2014). As part of their investigations, they developed models of *E. coli* airsacculitis (inflammation of the air sacs), turkey osteomyelitis complex (TOC), which is a term used to describe green colored livers, abscesses, and inflammation of the bones or joints (see Huff et al., 2000) and clostridial dermatitis (inflammation of the skin caused by *Clostridium* spp.), all of which are important production diseases of turkeys. Generally, larger bodied turkeys react more adversely to stress. For example, Huff et al. (2007) discovered that turkeys of the smaller E line (described in Section 13.2) took less time to resume typical behavior and activity levels (eating and drinking) compared to turkeys of the commercial line and F line (Huff et al., 2007). Similarly, Kowalski et al. (2002) reported differences in stress responses between turkeys of two commercial genetic lines that differed in body weight. Specifically, corticosterone levels were higher in turkeys of a faster growing heavy line compared to turkeys of a slower growing medium line following transport stress.

The differences between genetic lines extend to differences in disease susceptibility following stress. For example, when exposed to *E. coli* following dexamethasone injections or transport stress, the larger bodied commercial and F line turkeys reacted more adversely (higher heterophil/lymphocyte ratios) compared to turkeys of the smaller bodied E line (Huff et al., 2005). Mortality rates were also highest for commercial line turkeys (Huff et al., 2005). Huff et al. (2007) postulated that transportation stress is immunosuppressive in turkeys that have been selectively bred for faster growth rates because these turkeys have a "blunted hypothalamic–pituitary–adrenal (HPA) axis" that makes them more susceptible to opportunistic bacterial infections (Huff et al., 2007). Sex differences have also been reported: male turkeys had higher corticosterone levels following transport stress and higher activity levels in T maze and open field tests (Huff et al., 2007) than females. Based on other studies (Huff et al., 1999, 2006; Redig et al., 1985), Huff et al. (2007) concluded that male turkeys are more susceptible to the immunosuppressive effects of stress.

Stress and immune responses may be affected by the rearing environment, but more information is needed. One study compared innate immune parameters of turkeys reared in different rearing systems (Franciosini et al., 2011). Immune parameters (serum bactericidal activity and hemolytic complement levels) differed among turkeys with outdoor access and turkeys raised indoors, indicating that the rearing environment can affect the natural immunity of turkeys (Franciosini et al., 2011). However, before drawing any conclusions about the welfare benefits of any one system over another, it is important to note that the types of stressors differ among rearing environments. In particular, turkeys housed indoors may experience more social stress and stress due to higher stocking densities, whereas turkeys reared outdoors may experience stressors relating to temperature and weather extremes and predators.

13.3 Injurious pecking and aggression

Injurious pecking (head pecking, feather pecking, and cannibalism) and aggression are the major behavioral welfare issues of commercial domestic turkeys. Injurious pecking affects millions of turkeys annually and is a common occurrence in most commercial turkey flocks at one point or another. Severe pecking-associated injuries in commercial turkey barns reportedly account for as much as 58% of culls and mortalities (Duggan et al., 2014). Head pecking, which is pecking directed at the head, neck, or snood (Buchwalder and Huber-Eicher, 2003), is more prevalent among male turkeys than female turkeys and is associated with aggression (reviewed in Dalton et al., 2013). In contrast, feather pecking (the pecking, pulling, and sometimes removal of feathers of conspecifics) and cannibalism (the pecking and consumption of skin and tissue) are believed to be related to redirected foraging behavior, similar to the etiology of feather pecking among laying hens (Dalton et al., 2013).

Feather pecking is classified as gentle feather pecking when there is little damage to the recipient and the recipient usually does not react. In contrast, severe feather pecking manifests as forceful pecking and pulling of feathers, resulting in feather loss and feather damage, as can be seen in Fig. 13.4, and potentially eliciting a reaction from the recipient bird (Savory, 1995). Some birds may eventually stop reacting to being pecked (Rodenburg et al., 2013). Of the turkeys that are not culled before slaughter, an average of 6.6% of carcasses at the slaughter facility have been found with evidence of feather pecking (Allain et al., 2013). Severe feather pecking can lead to skin and tissue damage and cannibalism, resulting in mortality or necessitating culling (Savory, 1995; reviewed in Rodenburg et al., 2013).

In addition to the direct impacts on animal welfare, feather pecking may be associated with other welfare issues. Correlations have been found between indications of feather pecking on carcasses of market weight turkeys and leg problems, including arthritis, toe deviations, and footpad swelling (Allain et al., 2013; Table 13.1).

Figure 13.4 (A) Feather pecking can result in damage to various areas, such as the tail feathers where triangular sections of feather have been removed (B) (turkey has been marked with colored livestock marker on the right wing).

These leg problems can lead to lameness which is a welfare issue in and of itself. The relationship between feather pecking and leg problems is still poorly understood, but merits further investigation. It is likely that birds that have leg problems are less active and less mobile. These birds may become targets of feather pecking, further leading to a reduction in their welfare. Therefore it is important that birds that have difficulty in walking are identified early and treated or removed from the flock before these birds suffer further from injurious pecking.

There is strong evidence indicating a genetic basis for injurious pecking by laying hens (reviewed in Rodenburg et al., 2008), but limited information is available

Table 13.1 Pearson (r) correlations between evidence of feather pecking and arthritis, foot swelling, deviated toes, and scratches on turkey carcasses at slaughter (Allain et al., 2013)

Lesion or health condition	Pearson correlation coefficient (r)
Arthritis	0.39 ($P < .01$)
Foot swelling	0.49 ($P < .001$)
Deviated toes	0.51 ($P < .001$)
Scratches (> 5 cm or several scratches)	−0.48 ($P < .001$)

regarding the genetic basis of injurious pecking of turkeys. In a study comparing behavior of Nebraska Spot turkeys and commercial turkeys of a male line, Busayi et al. (2006) reported that the number of gentle feather pecks was higher among traditional line turkeys, but none of the traditional line turkeys required treatment for injuries, whereas 32% of male commercial and 15% of female commercial turkeys were treated for injuries. Their results indicate possible genetic differences in behavior (whether recipients of pecking move away or not) or differences in feather pecking (whether some birds are more prone to developing feather pecking). It is also possible that damage due to feather pecking is more severe and more visible in some genetic lines of turkeys due to differences in feather structure and feather density (Busayi et al., 2006). With only this single, published study examining genetic differences in feather pecking, our understanding of feather pecking behavior of turkeys remains very limited.

Unlike feather pecking which occurs in male and female turkeys, aggression is mainly reported to be a problem among male turkeys. Turkey toms not only direct aggression toward each other, but farm workers may also become targets of aggression. Aggression is associated with bird familiarity: turkeys are able to distinguish between familiar and unfamiliar turkeys up to a certain group size (Buchwalder and Huber-Eicher, 2003, 2004; reviewed in Dalton et al., 2013). Buchwalder and Huber-Eicher (2004, 2005) reported that levels of aggression directed at an unfamiliar tom were higher when the tom was introduced into a small group of six toms compared to a situation where an unfamiliar tom was introduced into a group of 30 toms. Based on these results, it was concluded that turkeys have a "limiting group size" beyond which they are incapable of distinguishing among individual turkeys (Buchwalder and Huber-Eicher, 2005). Therefore, flock size may be an important factor influencing the level of aggression in commercial turkey tom flocks, but until more information is available, it is not possible to speculate as to the exact relationship between flock size and aggression. In addition to group size, space also affected levels of aggression, with more aggression being directed at an unfamiliar tom in a small pen compared to a larger pen (Buchwalder and Huber-Eicher, 2004).

Currently, injurious pecking, whether from aggression or feather pecking, is managed in commercial turkey facilities through the use of beak trimming or by reducing the light intensity in the barn, or both. Beak trimming of turkeys is most commonly performed with infrared methods, but can also be performed using hot blade beak trimming. However, both beak trimming and reduced light intensity can be problematic for animal welfare. Hot blade beak trimming is associated with pain (e.g., Freire et al., 2008; Jongman et al., 2008; reviewed in Nicol et al., 2013) and infrared beak trimming, though considered to be more precise (Dennis et al., 2009), does not necessarily cause less short-term pain (reviewed in Nicol et al., 2013). Reduced light intensity may affect how the eye develops, causing vision problems, and is associated with reduced activity levels (e.g., Nickla et al., 2001; reviewed in Nicol et al., 2013). Until other alternatives are found, beak trimming, management of light intensity and photoperiod, and the use of environmental enrichment are the most practical options for controlling injurious pecking.

13.4 Footpad dermatitis and leg abnormalities

Footpad dermatitis and abnormalities of the musculoskeletal system impact the welfare of turkeys at all stages of production. Turkeys that experience these types of problems have locomotor difficulties and may have trouble reaching feed and water. Furthermore, turkeys that are unable to walk may become targets of injurious pecking.

13.4.1 Footpad dermatitis

Footpad dermatitis (FPD, pododermatitis) is routinely scored as part of welfare audits in the United States and Europe (Shepherd and Fairchild, 2010), highlighting the importance of FPD to animal welfare. Footpad dermatitis is characterized by inflammation of the footpad. Lesions and ulcers may be present on the bottom of the footpad and toes, which may lead to secondary bacterial infections and lameness (Clarke et al., 2002). In addition to the detrimental effects on animal welfare due to pain and lameness, FPD is economically important because turkeys with FPD have reduced growth rates (reviewed in Shepherd and Fairchild, 2010). Footpad dermatitis may also be associated with other conditions such as breast blisters and hock burns that further impact the quality and economic value of the carcass (reviewed in Shepherd and Fairchild, 2010). Hock burns and breast blisters are also types of contact dermatitis that share the underlying causes of FPD, but unlike FPD, there is no associated bacterial infection (reviewed in Shepherd and Fairchild, 2010).

It is possible to detect FPD as early as 3−5 days of age and the severity of FPD worsens as turkeys age (Bergmann et al., 2013). In an examination of over 5500 turkey poults, Bergmann et al. (2013) found that almost half of the poults had developed changes in the footpad by 22−35 days of age. A large percentage of commercial turkey flocks are affected by FPD. Da Costa et al. (2014) reported FPD in 95% of turkeys from 41 flocks in North Carolina, and others have reported incidences as high as 70% in turkey hens and 78% in turkey toms (see Mayne, 2005). Female turkeys are at a greater risk of developing footpad dermatitis compared to males (Bergmann et al., 2013; Vermette et al., 2016b), perhaps due to differences in the connective tissue of the footpad plantar surface, although this has not been examined (Bergmann et al., 2013).

Footpad dermatitis is a multifactorial problem that is influenced by several factors, including litter condition, drinker design, air temperature, humidity, ventilation, diet, group size and stocking density, sex, genetic line, and body weight (reviewed in Clark et al., 2002; Mayne, 2005; Shepherd and Fairchild, 2010). Litter moisture content is perhaps the most important factor affecting the development of FPD. Experimentally, FPD has been induced at litter moisture contents of at least 30% (Wu and Hocking, 2011) and 49% (Weber Wyneken et al., 2015), and FPD severity increases as litter moisture content increases (Weber Wyneken et al., 2015). In addition, FPD scores have been found to be more variable, indicating a wider range in footpad condition, in turkeys housed on wet litter compared to turkeys kept on dry litter (Hocking and Wu, 2013).

The detrimental effects of FPD on turkey welfare have been demonstrated in studies examining behavioral differences among turkeys housed on wet or dry litter and turkeys with differing levels of FPD severity. Results from two separate studies indicated that turkeys' activity levels decrease as litter moisture content increases (Hocking and Wu, 2013; Sinclair et al., 2015). In addition, behavioral sequences were found to be more varied and more complex for turkeys housed on dry litter compared to wet litter (Sinclair et al., 2015). As expected, behavior is affected by FPD severity: behaviors such as walking, standing, and environmental pecking, among others, have been reported to occur less frequently in turkeys with more severe FPD, which is indicative that FPD is associated with pain (Sinclair et al., 2015).

In addition to behavioral differences, further evidence of pain associated with FPD comes from studies examining behavioral differences in turkeys receiving analgesics and turkeys receiving saline. In the study by Sinclair et al. (2015), saline-treated birds housed on dry litter spent more time walking than saline-treated birds housed on wet litter, but no differences were found when birds were treated with analgesics, providing further evidence that FPD from wet litter is associated with pain (Sinclair et al., 2015).

13.4.2 Leg and skeletal abnormalities

Major skeletal abnormalities that impact turkey welfare include long bone distortions like varus (feet are turned inward while the hocks are turned outward) and valgus (feet are turned outward and hocks are turned inward) deformities and twisted leg, shaky leg (leg tremors), tibial dyschondroplasia (a cartilage plug at the proximal end of the tibia), and crooked toes. These conditions lead to lameness, culling, and mortality. Some of these disorders are heritable (valgus, varus, and crooked toes) (reviewed in Hocking, 2014).

There are numerous reports that the increase in growth rates and breast muscle of commercial turkeys has resulted in increased skeletal abnormalities and leg disorders. According to Quinton et al. (2011), there is a relationship between genetic selection for increased growth, which can lead to lower survivability and problems with walking ability as well as leg, foot and skin health, and leg problems. In addition to being selected for improved feed efficiency, modern commercial turkeys have been selectively bred for higher breast meat yields. The larger breast muscle not only impacts gait (Corr et al., 2003; Resch-Magras et al., 1993), but leads to a greater risk of fractures of the femur and tibiae due to the additional strain placed on these bones (Ferket et al., 2009). In a recent review, Hocking (2014) discusses the consequences of genetic selection on the health and welfare of turkeys and states that there is an association between genetic selection for productivity and leg disorders, but this association is sometimes exaggerated. Changing selection practices such that turkeys are selected based on walking ability could lead to improved survival and hip and leg health (Quinton et al., 2011).

In addition to genetic causes, other causes of leg and skeletal abnormalities include environment and management, diet and photoperiod (discussed in Section 13.5). The effects of environment and management on leg abnormalities in turkeys and chickens were reviewed over 20 years ago by Hester (1994). The main factors that were identified in her review as affecting leg abnormalities of turkeys include lighting, rapid weight gain, slippery flooring surfaces, environmental temperatures, humidity levels, and infectious diseases. Infectious causes of leg and skeletal problems in turkeys include osteomyelitis, caused by *Staphylococcus aureus*, synovitis caused by *S. aureus* and/or *Mycoplasma synoviae* (synovitis); and footpad dermatitis or bumblefoot which can be caused by *S. aureus* or management-related factors such as wet litter (Hester, 1994). More recently, Sharafeldin et al. (2015) demonstrated that lameness can be caused by turkey arthritis reoviruses which affect the gastrocnemius tendon of turkeys between 4 and 12 weeks of age.

13.5 Environment and management factors affecting turkey welfare

13.5.1 Lighting

There are several aspects related to lighting that need to be considered when discussing turkey welfare. These aspects include photoperiod (day length or number of hours of light), light intensity, the source of light (e.g., incandescent vs fluorescent), and the lighting program. Lighting programs include (1) constant lighting (e.g., 24 hours of light) or lighting programs that provide consistent amounts of light and darkness (e.g., 16 hours of light and 8 hours of darkness), (2) step-up lighting, whereby the number of hours of light is gradually increased, (3) step-down lighting, whereby the number of hours of light is gradually decreased, and (4) intermittent lighting, whereby periods of light and dark are interspersed throughout a 24-hour period.

Intuitively, turkeys raised under constant light would seem to fare worse than turkeys provided with a period of darkness. After all, turkeys, like other animals, have circadian rhythms that adjust to natural cycles in light and darkness. In general, overall mortality rates are higher when turkeys are not provided with a period of darkness (Table 13.2). However, injurious pecking and cannibalism are worse when turkeys are not reared in near continuous light. For example, studies have reported higher percentages of dead birds with signs of injurious pecking and higher incidences of cannibalism when (1) turkeys were reared under a photoperiod that included a period of darkness compared to constant (23 hours) light (Schwean-Lardner et al., 2016), and (2) when turkeys were reared under a photoperiod that gradually increased the amount of light provided compared to constant (23 hours) light (Classen et al., 1994; Newberry, 1992). However, the effects of photoperiod on injurious pecking and cannibalism need to be balanced with other effects on turkeys' welfare, such as eye deformities, rest, and mortality due to causes other than injurious pecking and cannibalism.

Recent work by Vermette et al. (2016a,b) suggests that turkeys need a period of darkness because rearing turkeys under (near) constant light leads to eye deformities and reduced activity levels which are hypothesized to be indicative of sleep deprivation (Schwean-Lardner et al., 2016). Intermittent lighting programs that provide short, alternating periods of light and dark also affect turkeys' vision. Sherwin et al. (1999) reported that intermittent lighting resulted in 40% of turkeys being visually nonreactive, suggesting possible blindness.

Although constant light reduces mortality due to injurious pecking, culling due to skeletal problems increases as photoperiod increases. Vermette et al. (2016a) reported that skeletal problems, including varus and valgus deformities and rotated

Table 13.2 Effects of near-constant (23 hours) light on turkey welfare[a]

	Welfare concern
Effects on health	• Eye abnormalities • Higher dorso-vetral diameter • Greater anterior–posterior depth • Greater eye weight • Poorer walking ability • Higher overall mortality • Increased culls and mortalities due to skeletal problems • Valgus–varus abnormalities • Rotated tibia • Wing and/or leg fractures • Muscular hemorrhage • Tibial dyschondroplasia
Effects on behavior	• More inactive resting • Less environmental pecking • Less drinking • Less feather pecking

[a]Information from (Classen et al. (1994), Newberry (1992), Schwean-Lardner et al. (2016) and Vermette et al. (2016a)).

tibiae, were more frequent when turkeys were reared under 23 hours of light compared to 14, 17, and 20 hours of light. Walking ability of turkeys also decreases as photoperiod increases (Schwean-Lardner et al., 2016).

Skeletal health is also affected by the intensity of the light. For example, male turkeys reared under a high intensity (20 lx) step-up lighting program to induce earlier sexual maturity were reported to have half as many leg abnormalities compared to male turkeys reared under a low intensity (2.5 lx) step-down lighting program (reviewed in Hester, 1994). Turkeys in the step-up lighting program were more active and the greater amounts of exercise in addition to earlier sexual maturation could have contributed to fewer leg abnormalities (reviewed in Hester, 1994). Hester (1994) concluded that light intensity needs to be combined with step-up lighting in order to have a positive effect on leg health of turkeys. Intermittent lighting programs also affect leg health, but the effects depend on the type of system that turkeys are housed in. Intermittent lighting reduces leg abnormalities in turkeys grown in "black-out" barns with no natural daylight (Hester and Kohl, 1989; Wilson et al., 1984; reviewed in Hester, 1994), but increases leg abnormalities in turkeys grown in curtain-sided houses as compared to constant light of 15L:9D (Clarke et al., 1993; reviewed in Hester, 1994).

While most research has examined the effects of photoperiod and lighting programs using experimental approaches where animals are placed in one lighting situation or another and the outcomes are recorded, another approach to improving animal welfare is to use preference tests or choice tests to "ask" animals what they prefer. Research has not examined turkeys' preferences for photoperiods, but evidence from work examining turkeys' preferences for light intensity suggests that turkeys prefer intensities that are as bright, or brighter, than what they were exposed to during rearing (Sherwin, 1998). When turkeys that were housed in light intensities of either 4 or 12 lx were given a choice of <1, 5, 10, or 25 lx, turkeys housed under 4 lx spent more time in a chamber illuminated at 5 lx than other intensities, whereas turkeys housed under 12 lx spent more time in a chamber illuminated at 25 lx than other intensities (Sherwin, 1998).

The preferences of turkey poults for light intensity were also tested by Barber et al. (2004). The preference for a particular intensity may depend on the behavior being performed and varies with age. When given a choice among <1, 6, 20, and 200 lx, 2-week-old turkeys spent the majority of their time, and performed all behavior (preening, standing, perching, etc.), in a chamber illuminated at 200 lx. Turkeys spent the least amount of time in the dimmest chamber. At 6 weeks of age, turkeys spent more time in 20 and 200 lx and performed resting and perching behavior in light intensities of 6, 20, and 200 lx, whereas other, more active, behavior (e.g., standing, preening, perching, feeding, drinking, among others) was mostly performed in intensities of 20 or 200 lx (Barber et al., 2004).

13.5.2 Environmental enrichment

Environmental enrichment is often used to improve animal welfare. In order for a change in an animal's environment to be considered as environmental enrichment, the enrichment must be biologically relevant, possess functional significance to the animal, and result in an improvement and not merely a change in the animal's environment (Newberry, 1995). A few studies have examined the impacts of different objects on injurious pecking among turkeys, and results vary depending on the types of objects used (reviewed in Dalton et al., 2013). In addition to examining the effects of intermittent lighting on injurious pecking among male turkeys, Sherwin et al. (1999) used a variety of objects as environmental enrichment, including straw, plywood boards to which screws, hooks, and chains had been attached, cabbages, plastic conduit, supplemental lighting and AstroTurf, among others. Intermittent lighting did not reduce injurious pecking, but wing and tail injuries resulting from injurious pecking were lower among groups of turkeys that were provided with environmental enrichment. Similarly, Moinard et al. (2001) demonstrated that injurious pecking-related injuries were fewer among male turkeys provided with supplemental UV light, visual barriers, and straw. In another study, Martrenchar et al. (2001) reported lower levels of injurious pecking and fewer pecking-related injuries in groups of male and female turkeys that were provided with bales of straw, reflective metal sheets with hanging chains and perches. Perch use declined after 6 weeks of age, indicating that perches may lose effectiveness as environmental enrichment as turkeys age. More recently, Duggan et al. (2014) examined the effectiveness of colored plastic balls at reducing injurious pecking among male turkeys in a commercial facility, but reported that plastic balls did not reduce injurious pecking. Huff et al. (2003) also used plastic balls, in addition to infant toys and mirrors, as environmental enrichment and examined the effects thereof on disease resistance of turkeys. Turkeys were tested in a T maze (discussed in Section 13.2) and turkeys classified as FAST differed from turkeys classified as SLOW in how they responded to the addition of objects to their environment: FAST turkeys had lower body weights and increased disease susceptibility at 8 weeks when challenged with Dexamethasone and *E. coli* at 5 weeks of age. Although the objects that were added to the turkeys' environment were intended as environmental enrichment (Huff et al., 2003), the objects were rotated daily and it is possible that the daily addition of new objects imposed an additional stress. Based on these few studies, it appears that injurious pecking is mitigated when a variety of objects are used, but care needs to be taken in how objects intended as environmental enrichment are provided. Further research is needed to identify effective and biologically relevant types of environmental enrichment for turkeys.

13.5.3 Space, stocking density, and group size

The amount of space that is available to an animal and how that animal uses the space is affected by the number of animals sharing that space. Therefore, space, group size, and stocking density (the amount of space available per animal or average body weight per unit of space) are related. The effects of each of these factors on turkey behavior and wellbeing are difficult to assess, especially because space, group size, and density are often confounded in scientific studies. Nonetheless, results from several studies suggest that welfare worsens as stocking density increases.

Stocking density is associated with numerous impacts on turkey welfare, including increased injurious pecking, disturbances of resting birds and bird health (reviewed in Marchewka et al., 2013; Erasmus, 2017). As stocking density increases, turkeys may be more likely to be disturbed by their flockmates (Martrenchar et al., 1999). High stocking densities also adversely impact some health-related conditions such as leg and foot health (e.g., Martrenchar et al., 1999), and breast blisters (e.g., Berk and Hahn, 2000). Respiratory problems, specifically airsacculitis (Noll et al., 1991), appear to worsen as stocking density increases. There is some evidence that lung lesions are more severe at higher stocking densities (Perkins et al., 1995), but other research found no association between lung lesions and stocking density (Zuidhof et al., 1993). In general, higher densities (greater than 29.3 kg/m^2 or 6 lb/ft^2) are associated with reduced body weight, reduced feed efficiency, and increased mortality rates.

There is a complex relationship between stocking density, animal welfare, and environmental and management factors (Dawkins, Chapter 11). For example, litter quality, ventilation, and air quality are affected by stocking density because more animals produce more waste, which requires appropriate litter management and ventilation rates in order to maintain turkey health and wellbeing. Therefore management is extremely important and can have impacts on turkey behavior and welfare beyond the impacts from stocking density alone.

13.5.4 Nutrition

Because of the relationship between fast growth and leg abnormalities, a lot of research has been dedicated to examining the effects of diet and nutrition on leg abnormities and footpad condition. The nutrition of turkeys used for breeding can also have lasting effects on leg health of the next generation of turkeys (Oviedo-Rondon et al., 2006). Oviedo-Rondon et al. (2006) reviewed the nutritional factors affecting leg health of turkeys. Nutritional factors important in leg health include vitamins (D, A, C, K, and B), minerals (Ca, P, Na, Cl, Zn, Se, Cu, and Mn), protein and amino acid (methionine, cysteine, cysteine, and the metabolite homocysteine) levels, fatty acid levels, feed intake, and feeding and management practices.

Since the review of nutritional factors affecting skeletal abnormalities by Oviedo-Rondon et al. (2006), there have been further insights into the effects of certain dietary factors. For example, Ferket et al. (2009) reported that dietary supplementation with commercially available organic trace minerals (Zn, Mn, and Cu) not only reduced several types of leg deformities (e.g., varus deformities) in growing male turkeys between 12 and 20 weeks of age, but also increased bone breaking strength, especially when given in combination with 25-hydroxycholecalciferol, a more bioavailable form of vitamin D.

The effects of dietary calcium (Ca), phosphorus, chlorine (Cl), and sodium (Na), as well as phytase, continue to receive attention because of their impacts on skeletal health and litter moisture, a major cause of footpad dermatitis (discussed in Section 13.4.1). Roberson (2009) examined the effects of various levels of dietary phosphorus and calcium on growth and bone integrity in commercial male turkeys.

Their results revealed that body weight was lower in turkeys fed at National Research Council (NRC, 1994) recommended levels (Low) of nonphytate phosphorus and diets that were 0.06% higher than NRC recommended levels (Med) compared to turkeys fed at 0.1% higher than the med diet (High) and 0.1% higher than the High diet. In addition to lower body weights, turkeys fed with the Low diet had higher incidences of bone fractures and reduced walking ability, indicating that feeding nonphytate phosphorus at levels above NRC recommended levels resulted in improved growth and better skeletal integrity (tibia breaking force) compared to NRC recommended levels.

Similarly, the level of calcium can affect skeletal properties and body weight. For example, Tatara et al. (2011) reported improved skeletal properties and increased body weights in turkeys provided with 95% or more of NRC recommended calcium compared to those provided with 85% of NRC recommended calcium. Bone properties are also affected by Na levels. Indeed, Jankowski et al. (2012) reported that the levels of Na at 0.17% and Cl at 0.40% were most advantageous for turkey health, compared to Na levels at 0.07%, 0.12%, and 0.22% and Cl levels at 0.23%, 0.30%, and 0.49%, because these higher and lower levels of Na and Cl, respectively, negatively impacted body weight, strength of the tibia, and gut metabolism. The incidence of FPD was highest in turkeys fed with the highest level of NaCl because Na levels affect water intake and therefore litter moisture (Jankowski et al., 2012). These results are supported by those of Farahat et al. (2013) who demonstrated that dietary chlorine levels of 0.4% or higher had detrimental effects on footpad condition and litter moisture.

In addition to the effects on skeletal health, dietary factors are also important in boosting the immune function of turkeys. With the ever increasing concerns over antibacterial resistance, there is interest in developing alternatives to the use of antibiotics. One area that has received a lot of attention is the use of yeast cell products as dietary additives to improve immunocompetence. The effects of yeast cell products on the immune function of chickens and turkeys have been reviewed by Świątkiewicz et al. (2014). Overall, dietary supplementation with yeast products is beneficial in enhancing immune function, thereby increasing resistance to disease (Świątkiewicz et al., 2014). Huff et al. (2010, 2011, 2013, 2014) specifically examined the effects of providing supplemental yeast extract or yeast culture on disease resistance following stress. Compared to controls that were not inoculated with *E. coli* or subjected to transportation stress, yeast supplementation increased the number of peripheral heterophils and resulted in *E. coli* being isolated from fewer birds compared to birds that did not receive any yeast supplementation (Huff et al., 2010).

Supplemental yeast extract was also beneficial in reducing the number of turkeys that developed clostridial dermatitis when turkeys were immunosuppressed with dexamethasone (Huff et al., 2014). Sex differences were found for the effects of yeast extract supplementation: providing supplemental yeast extract resulted in reduced serum corticosterone levels in male, but not female turkeys, and resulted in increased oxidative burst activity of heterophils, which is an indicator of immune response activation (Huff et al., 2011). Using yeast culture instead of yeast extract has beneficial effects as well. Transportation of turkeys had a negative impact on welfare because it resulted in stress, reduced body weight, and reduced feed efficiency, but providing yeast culture supplementation during this period of stress reduced the negative impacts of transportation stress and an *E coli* challenge on feed efficiency (Huff et al., 2013).

13.6 Welfare issues of turkey breeders

Research investigating turkey breeder welfare is very limited and has focused on feed restriction and femoral fractures. However, turkey breeders are kept in production much longer and handled more frequently than turkeys raised for meat, which may present unique welfare challenges that require further investigation.

13.6.1 Stress due to frequent handling

Frequent handling during artificial insemination of breeder hens and semen collection of breeder males is a potential welfare issue because of the ability to cause fear and stress during capture and handling, and injury during the insemination or process of semen collection if the method is not performed correctly. However, it is important to note that no research has examined stress and welfare issues resulting from frequent handling. Females are captured and restrained for insemination which may adversely impact welfare. However, the entire process of insemination is rapid, taking a few seconds if done properly. No published research has examined the impacts of artificial insemination on turkey breeder hen welfare. Turkey toms are also captured and then "milked" during the process of semen collection. If not done properly, the semen collection process can result in injury or infections. There is some evidence (discussed below) that semen collection may impose an additional stress on the skeleton of the male breeder turkey, contributing to leg fractures (Crespo et al., 2000, 2002).

13.6.2 Feed restriction

Throughout this chapter, the effects of genetic selection for increased feed efficiency and increased body weight on turkey welfare have been discussed. Another effect of increased body weight is that it is associated with adverse effects on reproductive performance. Consequently, weight is managed by (1) using ad libitum feeding with reduced protein levels or (2) using feed restriction (controlled feeding) whereby the amount of feed provided daily is reduced (Aviagen Turkeys, 2015). Feed restriction may lead to chronic states of hunger, resulting in poor welfare. However, the effects of feed restriction on turkey welfare may depend on the age of the birds. Hocking (1999) examined behavioral and physiological differences among commercial male and female turkeys that had been fed ad libitum and commercial turkeys that had been feed restricted from 4 weeks onward (males and females) or starting at 18 weeks of age (males). Turkeys that were feed restricted since 4 weeks of age spent more time in pecking walls and other environmental features, whereas ad libitum fed turkeys and turkeys that were restricted starting at 18 weeks spent more time in preening (Hocking, 1999), which is indicative of poorer welfare in feed restricted turkeys.

On the other hand, high body weight gain may be associated with health problems in breeder turkeys, necessitating some feed restriction. Hocking (1999) demonstrated that plasma levels of lactate dehydrogenase, an enzyme associated with changes in tissue function and cell damage, were lower in feed restricted turkeys, which may be associated with reduced muscle and cardiovascular disease compared to ad libitum fed turkeys. Based on these results, Hocking (1999) concluded that feed restriction of male turkeys after 18 weeks of age was associated with few negative effects on turkey welfare. However, it appears that welfare is adversely affected when male and female turkeys are feed restricted as early as 4 weeks of age.

13.6.3 Leg problems

As discussed in Section 13.4, leg problems are present at all stages of production. In male turkey breeders in particular, femoral fractures have been found to be associated with lameness and mortality (Crespo et al., 1999). Turkeys with femoral fractures have difficulty in reaching feed and water and may die from being pecked by other turkeys (Crespo et al., 2002). The femoral fractures may be due to overuse from being handled repeatedly for semen collection (Crespo et al., 1999) or a body weight that is larger than can be supported by the skeleton (Crespo et al., 2000).

13.7 Conclusions and implications

Advances in housing, management, and selective breeding practices have created a turkey industry that is much larger and produces heavier birds than what was possible several decades ago. Many of the welfare issues in the turkey industry have been linked with faster growth rates and heavier body weights. However, it is important to remember that the major welfare issues of turkeys are multifactorial in nature, and are affected by environment and management factors in addition to being associated with genetic selection for increased body weight. Some welfare issues are problematic at all stages of production, such as injurious pecking and leg problems. Other welfare issues are specific to particular segments of the industry, such as feed restriction of breeding stock. With these welfare issues in mind, several areas for future research are highlighted below.

Because of the links between selective breeding for production traits and leg problems, research examining genetic causes of welfare problems continues to be important. In order to address some of the most pressing welfare issues, such as injurious pecking and leg problems, genetic selection should focus on health and longevity (Hocking, 2014), and not only production parameters. Furthermore, fundamental research aimed at understanding the genetic basis of individual differences in fear and stress responses and how these individual differences are associated with differences in productivity may provide a means of improving welfare without compromising productivity.

Although it may be possible to resolve some welfare issues through genetic selection, environmental and management factors will continue to be important in improving turkey welfare because animals are products of both their genes and their environment. A considerable amount of research has been dedicated to understanding the impacts of light and lighting programs on turkey welfare. However, injurious pecking continues to be a problem in turkey flocks. Further research examining the causes of injurious pecking and alternatives to using low light intensities and beak trimming to manage injurious pecking is warranted. In addition to injurious pecking-focused research, work is needed to identify management and environmental factors that can be used to improve skeletal health of turkeys produced for meat as well as turkeys used for breeding. Additionally, turkey breeders are kept in production for relatively long periods of time; therefore, there is the potential to greatly improve their welfare if alternatives to feed restriction can be developed.

The number of animal welfare certification programs has increased steadily in recent years. Each of these programs requires that a set of standards be met in order for certification to be granted, yet there is little scientific information available to inform these certification programs. Stocking density has major impacts on the welfare of turkeys (e.g., Marchewka et al., 2013); however, the amount of space that turkeys require to perform various behaviors is poorly understood. Additional scientific information is also needed to develop measures or tests that can be used to assess turkey welfare. One welfare assessment protocol specifically designed for turkeys has been developed (Animal Welfare Indicators, AWIN, 2015). The AWIN protocol was designed to be used for the on-farm welfare assessment of intensively housed turkeys prior to slaughter and uses the transect method to collect data (see Marchewka et al., 2015). The AWIN protocol is beneficial from an animal welfare perspective because use of the protocol does not require turkeys to be handled and permits various animal-based indicators of welfare to be used (e.g., lameness, feather pecking, and aggression). Further research is needed to inform welfare assessment protocols and standards used as part of certification programs, especially where turkeys are raised in alternative systems (e.g., free range).

Together with the increase in animal welfare certification programs, interest in alternative production systems such as free range and organic systems is increasing. However, these systems are not without challenges to turkey welfare. Organic, and therefore antibiotic-free production, is increasing, but antibiotic-free production brings challenges for dealing with disease. Research into alternatives to antibiotics is needed. With free range systems, the risk for diseases such as avian influenza is higher, necessitating strict biosecurity measures to prevent disease from spreading. The research into using yeast cell products and yeast extract as dietary additives for boosting turkeys' immune systems (Huff et al., 2010, 2011, 2013, 2014) is promising. Further research into the link between nutrition and turkey welfare will open up a host of possibilities for not only improving immune function of turkeys, but addressing other welfare issues as well, such as skeletal problems and footpad dermatitis.

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Part V

Emerging issues

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The future of poultry pest management

14

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14.1 Introduction

Like most vertebrate animals, the poultry we raise and use for agriculture are hosts for many parasites and attract pestiferous insects (Axtell and Arends, 1990; McDougald, 2013; Ruff, 1999; Yazwinski and Tucker, 2008). Quite a few parasites can directly harm or kill poultry, or can transmit pathogens to them. This is especially apparent if conditions encourage parasites or if no management strategy is implemented. With the increasing rural/urban interface, these pests or parasites can become a nuisance to neighboring residents. Human contact with poultry, especially in backyard or hobby flock situations, carries a number of risks for zoonotic diseases that might be transmitted to people via poultry (Agunos et al., 2016). Zoonoses are mostly bacterial and viral agents, but some animal parasites also can cause human pain and suffering, such as bird mites that may bite people. For the purpose of this chapter we will focus on poultry parasites that include protists (protozoa) such as *Eimeria*, nematodes such as *Ascaridia*, and arthropods such as mites, lice, fleas, and flies. We are excluding pathogens that include bacteria, viruses, and other groups of microorganisms (e.g., *Mycoplasma* spp.).

While all species of poultry that we raise for agriculture are susceptible to parasites, management practices are critical in dictating the type and severity of infestation. For example, broilers used for meat production and egg-laying chickens are the same species, but northern fowl mites are more prevalent and more economically important in laying hens. This is primarily because broilers mature rather quickly and are not housed for long periods of time like egg-layers. The period of time poultry are housed is also important for parasites of other commercially raised poultry species such as turkeys. While this chapter will include discussion of many types of poultry parasites with varying degrees of host specificity, the main focus will be on parasites of laying hens. It is important to keep in mind that as management in other poultry systems changes, parasites likely will be affected as well.

The chapter is very timely because much of the world (especially Western Europe, North America, Australia, and parts of Asia) is in the midst of a massive change in animal welfare sensitivity and awareness. Accompanying this shift are increasing concerns regarding traditional pesticide use and possibilities for food or environmental contamination. It is vital that our society, and especially consumers, producers, and regulators of poultry and poultry products, realizes that these changes in turn affect parasites. Cultural aspects, such as housing design and how

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poultry are raised or handled, can dictate the parasite species found, their numbers and damage potential, and how they might be controlled. A key component of animal welfare is freedom of animals from pain, injury, and disease (Farm Animal Welfare Council, 1991) and we do not want to create new or more severe parasite problems as we try to improve other aspects of animal welfare! Parasites and their control must be part of the conversation as we propose or implement comprehensive management changes.

14.2 The poultry pest complex

It is convenient to segregate poultry parasites and pests into one of three groupings, based on the intimacy of the parasite–host relationship. The first and most intimate category is parasites that complete essentially their entire life cycle on or in the host, even if those parasites' eggs are away from the host and in the environment for some time period. Second are parasites that need direct host contact for partial completion of the life cycle, but also use the environment or other hosts for a significant part of the life cycle. Third are parasites or pests that exist in the bird environment (e.g., feed, bedding, or feces) but do not directly use the live bird itself as part of their life cycle. Some important poultry parasites and pests are illustrated in Figs. 14.1 and 14.2.

Figure 14.1 Ectoparasitic arthropod pests of poultry. Clockwise from upper left, *Ornithonyssus sylviarum* (northern fowl mite), *Menacanthus stramineus* (chicken body louse), scaly leg mite (*Knemidokoptes mutans*), and *Echidnophaga gallinacea* (sticktight flea). *Source*: Photos by authors; scaly leg photo courtesy of A. Yzaguirre.

Figure 14.2 Selected internal poultry parasites and temporary/environmental arthropod pests of poultry systems. Clockwise from upper left, *Eimeria tenella* (coccidian) sporulated oocysts, tapeworm (probably *Choanotaenia*) associated with the larger diameter chicken intestine, *Cimex lectularius* (bedbug), *Alphitobius diaperinus* (litter beetle), larvae of *Musca domestica* (house fly), and aggregation of *Dermanyssus gallinae* (poultry red mite).
Source: Photos by authors. Tapeworm photo courtesy of Dr. N. Hinkle, Department of Entomology, University of Georgia. Red mite photo courtesy of Dr. M. Mul, Wageningen UR Livestock Research, Netherlands.

14.2.1 Permanent parasites

Coccidia (*Eimeria* spp.) are single-celled protists (protozoa), and the more virulent species are infamous bird killers that can have major economic consequences (Williams, 2005). They occupy the intestinal tract of birds, infective forms pass out with bird feces, and those forms are transmitted to new birds by accidental ingestion. This transmission pattern is called "fecal–oral" (direct life cycle). Many of the parasitic helminths have this same basic transmission pattern (Yazwinski and Tucker, 2008), although some use intermediate hosts (e.g., beetles or earthworms) which in turn are ingested by birds (indirect life cycle). Examples of parasites using intermediate hosts include the roundworm *Ascaridia* spp. and tapeworms such as *Raillietina* spp.

Several arthropods also fall in the permanent parasite category. These include the northern fowl mite *Ornithonyssus sylviarum*, the scaly leg mite *Knemidokoptes mutans*, and chicken lice such as *Menacanthus stramineus*. These ectoparasites usually infest new birds by direct or close contact among birds, though northern fowl mites in particular may survive well off-host in between flocks (Chen and Mullens, 2008). Host specificity varies greatly even among permanent parasites. For example there are some helminth species that can survive only in a certain species of poultry (McDougald, 2013). On the other hand, the mite *O. sylviarum* is found on at least 72 bird species (Knee and Proctor, 2007) and thus can travel into a poultry operation on other hosts (e.g., sparrows), including being transported by rodents (Miller and Price, 1977). The type of transmission (direct or indirect) of these permanent parasites can play a role in their potential prevalence and severity in different housing systems.

14.2.2 Temporary parasites

Temporary parasites use the bird's body for part of their life cycle, for example as a food source, but live off-host for significant time periods. Some life stages do not interact with the host at all. Temporary parasites are currently some of the worst arthropod threats to laying hens as developed countries switch from conventional cages to alternative housing systems (Sparagano et al., 2014). Examples include the red mite, *Dermanyssus gallinae*, and sticktight fleas, *Echidnophaga gallinacea*. Red mites, also called chicken mites, need small cracks and crevices close to where the birds roost or nest, because the mites hide there and then come out at night to blood feed (Sparagano et al., 2014). This is also the case for soft ticks (*Argas* spp.) and bedbugs (*Cimex* spp.). Adult sticktight fleas attach to birds, especially around the head, but the eggs, larvae, and pupae are in soil and litter debris, where larvae feed on organic material and excess blood that the adult fleas excrete (Parman, 1923). Having few cracks and crevices in which they can hide helps prevent mites, ticks, and bedbugs. If there is no soil/litter contact by the birds, sticktight fleas will not be able to develop and reproduce.

14.2.3 Environmental pests

Pests like house flies (*Musca domestica*) or litter beetles (*Alphitobius diaperinus*) can be abundant in favorable environments near birds, especially when those birds are held at high densities. Feces accumulate under birds held on slats or in cages, and this is an attractive place for flies to lay their eggs and for larvae to develop. Moist organic debris mixed with spilled feed and feces under water lines is favorable for litter beetles. Beetles can cause serious damage by burrowing into poultry house insulation (Vaughan et al., 1984). Beetle larvae which dig into insulation and pupate can in turn be targeted by insect-eating birds, which greatly exacerbates this insulation damage. Adult flies and immature and adult beetles also have the potential to transmit or harbor poultry pathogens such as *Salmonella* or Newcastle virus (Chakrabarti et al., 2007; Crippen et al., 2012; Wales et al., 2010). Litter beetles are the intermediate host for chicken tapeworm (*Choanotaenia infundibulum*) (Elowni and Elbihari, 1979) and, because of their long life span (up to 12 months or more), beetles have the potential to be persistent reservoirs for tapeworms or other pathogens between flocks. Adult flies and beetles may disperse in high numbers to neighboring properties and become human pests. This can result in intervention from local health departments and/or lawsuits which may be severe enough to close down poultry operations (Thomas and Skoda, 1993).

14.3 Production systems influence pest complexes and severity

Production systems, and especially housing, play an important role not just in animal welfare, but also in potential parasite diversity and severity (Elson, 2015; Lay et al., 2011; Sossidou et al., 2011). Housing governs how hospitable the environment is for parasites, such as availability of hiding places, presence of soil or intermediate hosts, or suitable temperature and humidity. Housing also governs the level and intensity of birds' interactions with one other. A fundamental tenet of epidemiology, certainly applicable to poultry parasites, is what is called the 20/80 rule (Woolhouse et al., 1997). This recognizes that infection in a host population is typically highly heterogeneous, and 20% of available hosts in a population may be heavily or persistently infected and thus will be responsible for 80% of the transmission potential. The size of the interacting host pool is an important driver of how intense, widespread, and persistent a parasite outbreak will be. For example, hens in a small cage may directly contact fewer than ten other birds, while hens in an aviary might make direct contact with hundreds or thousands of other hens (or their feces) over time. The latter provides far more opportunities for parasite transmission, because there is a much larger number of hosts, with varying degrees of parasite infestation and susceptibility, for parasites to use.

14.3.1 The European red mite example

As a cautionary tale, the European experience with the red mite *Dermanyssus gallinae* (Sparagano et al., 2014) is worth careful scrutiny. The European Union banned conventional cages for egg-layers by 2012, though by 1999 the Scandinavian countries were already moving in the direction of enriched (furnished) cage or cage-free systems for welfare reasons. Simultaneously some pesticide options for mite control were banned (Sparagano et al., 2009). European scientists quickly demonstrated that the conventional cage alternatives encouraged *Dermanyssus* by providing harborage and complicating mite control efforts (Hoglund et al., 1995; Sparagano et al., 2009). Subsequently red mites vaulted to key pest status across Europe, and adequate control is still difficult (Mul et al., 2009; Sparagano et al., 2014). Estimates from several years ago show that red mite costs European producers about €130 million per year; detailed data for some countries are not available, but

France, for example, spends an estimated €4 per 100 hens per year for poultry red mite control (Sparagano et al., 2009, 2014). Given slim profit margins, such expenditures are rather severe for egg producers.

The United States is now heading in the same direction as western Europe did 10–20 years ago. California's Proposition 2, which passed in 2008 and was implemented by 2015, requires that producers provide much more space per hen (essentially eliminating the use of conventional cages), and mandated housing changes based on perceived hen space needs (Mench and Blatchford 2014) are also occurring in some other USA states. The USA shell egg industry as a whole is beginning to phase out conventional cages in favor of cage-free systems, as retailers demand an increased supply of eggs from these systems. The industry thus needs to be especially vigilant for *Dermanyssus*, which is already present in wild bird nests and backyard chicken flocks (Murillo and Mullens, 2016a; Roy and Chauve, 2007). There are also other potentially very bad pests, such as sticktight fleas, lice, other mites, or soft ticks, that still exist in backyard flocks, but that have not been seen in modern, large-scale commercial poultry production for many years (Murillo and Mullens, 2016a).

14.3.2 Pests will be pests

Some pests can flourish on birds across a wide range of housing or management types. Other parasites, especially if they use multiple hosts, are difficult to predict because we may not know the source of an infestation. The permanent ectoparasitic arthropods, northern fowl mites and chicken lice, thrive on birds regardless of how they are housed (Martin and Mullens, 2012). Caged or cage-free chickens in close proximity to one another provide permanent ectoparasites ample opportunity to spread and cause damage to their hosts, though their severity is greatly influenced by beak condition. A bird's beak is a key grooming tool, and arthropods can be effectively crushed or removed from the skin and feathers if the upper and lower mandibles meet well at the tip, especially with upper mandible overlap (Clayton et al., 2005, 2010). Even in flocks without beak trimming, individual birds with damaged beaks often have more of these ectoparasites. Commercial hot blade beak trimming, which may be desirable or necessary to prevent cannibalism or feed waste, predisposes birds to problems with ectoparasites (Mullens et al., 2010). There is some evidence, however, that newer precision infrared beak trimming and the associated subsequent beak regrowth may allow laying hens to regain some grooming capacity and reduce ectoparasites relative to the older trimming methods (Murillo and Mullens, 2016b).

14.4 Laying hen housing systems

14.4.1 Cages for laying hens: Good for a few parasites, bad for most

Laying hen housing systems are described in more detail in Karcher and Mench, Chapter 1. Both conventional and enriched cages permanently confine the hens.

Enriched cages allow more space per hen and have added structures including perches and scratchpads, providing some hiding opportunities for parasites and complicating treatment. However, certain aspects of parasite occurrence and management will be similar in both of these types of cage systems.

Conventional and enriched cages are excellent for efficient transmission of ectoparasites because of frequent direct hen contact, which allows parasites to disperse readily. Dispersal of parasites, like mites, along rows of cages also can be facilitated by those parasites being carried on egg collection belts. High hen densities in cages (especially conventional cages) also concentrate feces. If feces are allowed to accumulate, especially along with spilled food, it can promote pests such as house flies and litter beetles. Despite other welfare concerns, however, it is clear that cages either exclude or keep many other parasites from becoming serious issues. Parasites that require fecal–oral contact for transmission, such as coccidia and many internal nematodes, generally do not do as well in cages because feces drop through the cage floor and thus the infective stages are separated from the hens, reducing or breaking the transmission cycle. However, even in cages coccidia exposure may be high enough to cause disease (Price et al., 2014).

Parasitic helminth infections are relatively rare in caged hens (Permin et al., 1999) but have recently been found to be ubiquitous in noncage European organic systems, with a prevalence averaging 70% for *Ascaridia*, 29% for *Heterakis*, and 14% for *Raillietina* (Thapa et al., 2015). Similarly, for indirect life cycle parasites, intermediate hosts like earthworms or beetles are either absent or separated from the hens in cage systems. Cages separate hens from the soil environments needed for some pest life stages, such as immature sticktight fleas. Fewer hens per cage also limits effective host population size and the degree of sharing of some parasites via intimate contact. If one caged hen has a fecal–oral parasite, it is likely to transmit it only to its cage mates.

Conventional cages tend to lack cracks and crevices near the hens, so temporary parasites such as red mites, soft ticks, or bedbugs do not have safe daytime harborages. In contrast, enriched cages can provide good harborage for nest-dwelling parasites such as *Dermanyssus* (red mites), *Argas* spp. (soft ticks), or *Cimex* spp. (bedbugs).

Control for many parasites in conventional cage systems has relied on pesticide sprays or administration of antibiotics or parasiticides. Sprays are fairly easily applied from underneath the cages, wetting the vent and abdominal skin and feathers where ectoparasites live. Pharmaceuticals can be administered at the flock level via water lines or feed troughs, allowing their use across poultry systems. Spray treatments in enriched cages are possible but probably will be less effective than in conventional cages due to physical impediments (nest boxes, scratch pads, and perches). Spraying from below might still be possible, but it can be difficult to insert a spray device into what often is a very narrow gap, and hens in a nest box or above a scratch pad at the time of treatment might escape treatment altogether.

Indoor systems can be advantageous to parasites because they have relatively stable environmental conditions, favorable temperatures, and no rain to drown the parasites or direct sunlight to kill them. The red mite *D. gallinae*, for instance, does best at temperatures between 10°C and 35°C and relative humidity (RH) above 70% (Nordenfors et al., 1999). But indoor systems may also provide an opportunity to intentionally alter the environment to control parasites. Cages mostly limit parasite harborage and activity to the cages and immediate area, where the treatment or cleaning efforts can be concentrated. During inter-flock periods producers can substantially manipulate such environments by doing things like heating them or drying the houses (Mul and Koenraadt, 2009). Survival times (LT_{50}) for off-host protonymphs of the northern fowl mite *O. sylviarum* are 18 days at 15°C and 85% RH, but drop to only 2 days at 33°C and 31% RH (Chen and Mullens, 2008).

Managing habitats can be somewhat complex and must be target-specific. The roundworm *A. galli* has eggs that can resist some humidity or temperature stresses, but they need more than 70% RH and embryonate more quickly at moderate temperatures (20−30°C), accelerating the transmission cycle (Tarbiat et al., 2015). Most parasites have favored ranges of temperature or humidity, so exposing sensitive parasite stages to high or low temperatures or low humidities at the right time often can help control them. High humidity similarly tends to favor *Eimeria*. So high humidity might be bad overall. But the complexities are illustrated by the fact that higher humidity can become advantageous in helping producers deal with *Eimeria* at certain times. When producers use a live coccidial vaccine, which may be a relatively weak pathogen but one that will still impart immunity, they want recycling to occur in the flock to let that *Eimeria* infect all the hens and establish full immunity (Price et al., 2014). Low humidity in that case might cause the vaccine strain to perform poorly.

Moving away from cages toward alternative housing, a continuum exists. It includes various indoor cage-free configurations such as aviaries, and free-range or pastured flocks. Unfortunately, few studies have been conducted to carefully survey bird parasites along this housing continuum, though we can use the limited survey information and general knowledge of parasite life cycles to predict trends. We have summarized expected parasite problems in the different housing types in Table 14.1.

14.4.2 Cage-free housing

In cage-free systems, where large numbers of birds make frequent contact with one another and their feces, the effective host pool and risk of parasite transmission increases overall. Unfortunately then, noncage systems also tend to be "parasite-friendly" to varying degrees and we need to think carefully about how to prevent or control parasites in these systems.

Indoor cage-free systems allow frequent and direct contact among birds and their feces. They are protected against environmental degradation (sunlight, temperature extremes) and from rain. The substrate or litter tends to be rather dry except for feces or water leaks. Litter consists of bedding material, plus liberal amounts of feces, which may be on soil, concrete, or some other substrate. These environments usually have lots of cracks and crevices, such as nest boxes, roosts, or other structural features. Certain parasites like red mites or those using fecal−oral transmission can do well in this style of housing, with lots of hosts (birds) to fuel outbreaks.

Table 14.1 Prevalence of key poultry parasites by housing type[a]

	Housing type			
	Conventional cages	**Enriched cages**	**Cage-free indoor**	**Free range/ pasture**
Permanent parasites				
Coccidian (e.g., *Eimeria* spp.)	+ +	+ +	+ + +	+ + +
Nematodes (e.g., *Ascaridia* spp., *Heterakis gallinarum*)	−	+	+ + +	+ + +
Ornithonyssus sylviarum (northern fowl mite)	+ + +	+ + +	+ + +	+ + +
Knemidokoptes mutans (scaly leg mite)	−	−	+	+ +
Lice (e.g., *Menacanthus* spp.)	+ +	+ +	+ +	+ +
Temporary parasites				
Dermanyssus gallinae (red mite)	+	+ +	+ + +	+ + +
Cimex lectularius (bed bug)	−	+	+ +	+ +
Echidnophaga gallinaceae (sticktight flea)	−	−	+	+ +
Environmental pests				
Alphitobius diaperinus (darkling beetle)	+ +	+	+ + +	+
Musca domestica (house fly)	+ + +	+	+	+

[a]Absent (−); Present but not abundant (+); Common (+ +); Abundant and often damaging (+ + +)

High bird densities might suppress fly or beetle development overall by disturbing the habitat enough to hamper insect development or birds may eat the insects and perhaps control them that way. Sheltered places away from birds, such as under feed or water lines, beneath slats, or along walls, can serve as high-density sources of such organisms. Sticktight fleas might establish themselves in these systems if moist, relatively undisturbed substrate is maintained for the larvae.

Free-range or pasture settings vary in their potential to cause pest problems depending on individual farm habitats. In temperate zones, parasite numbers might fluctuate drastically according to season. Warm, moist summer conditions favor many parasites, while colder weather greatly slows their development and may even temporarily stop transmission altogether. If birds are at low densities, scattered feces tend to dry quickly or be dispersed. Serious fly issues should not arise, unless there are areas of concentrated feces or spilled feed. Hens can often effectively control flies by eating them when in direct contact with larval development sites. Nest-dwelling parasites, like *Dermanyssus*, can still find harborage in sheltered areas near where hens spend the night, often a mobile coop with nest boxes or some equivalent.

Sticktight fleas have the potential to thrive in free-range or pasture. Habitats near birds can be suitable for their larvae, and adult fleas can be transmitted to poultry by wild animals, such as ground squirrels or other rodents.

Moist soil and plants can be an excellent habitat for many fecal–oral parasites such as *Eimeria* or nematodes. In fact, the free-range or pasture condition is the most natural ones for many parasites; they evolved under those conditions and the diversity of species and their ability to survive in this system should exceed that of any other poultry production setting.

14.5 Nonorganic and organic pest control options in alternative systems

Here we define organic systems as those adhering to the U.S. Department of Agriculture's animal agriculture guidelines (USDA, 2013) for the food products to be labeled and marketed as "organic." Briefly, these include poultry being cage-free, allowed year-round outdoor access to soil, on certified organic land, raised according to animal health and welfare standards, fed organic feed, and managed without feed additives that otherwise might be common (e.g., antibiotics). Most drugs or antibiotics are banned in organic production, and if used they disqualify the animal or products from being sold as organic. Vaccines are generally acceptable. The Organic Materials Research Institute (OMRI) maintains lists of materials that are approved for use in organic systems (OMRI, 2017). These include pesticides such as plant essential oils (examples are thyme, geraniol, peppermint, rosemary, or garlic) (George et al., 2010) or inert materials such as diatomaceous earth (DE) (Murillo and Mullens, 2016b).

It is vital for the public to realize that many natural products marketed for parasite control are not regulated by the EPA like conventional pesticides. The natural products have usually therefore not undergone extensive or rigorous scientific testing, or perhaps any proper efficacy testing at all. In some cases, materials may have undergone laboratory bioassays, but their use and efficacy in the field remains untested. Testimonials abound for such materials, but testimonials are in no way comparable to fair or thorough scientific evaluation. Most OMRI materials are generally regarded as safe for people or animals, but active ingredients may be unknown or highly variable among marketed products, including concentration of active ingredients, what the active components are, how they work against parasites, or which parasites or stages might be affected. In certain cases natural products may still be harmful if improperly used, for example inhalation of DE particles (silicosis).

The range of permitted control products is substantially reduced in organic systems, and the nontraditional pesticides that can be used are in general not as well tested. This makes parasite control in organic systems a particular challenge, as those systems need to rely on parasite control methodologies without synthetic pesticides.

14.5.1 Biosecurity and the difference between eradication and management

Prevention of parasites is the best line of defense. Biosecurity in poultry systems is perhaps best considered in a series of zones, from the primary zone close to or even within the poultry house itself to the secondary zone (larger farm or site), and finally a tertiary zone that might include, for example, shared sites such as feed mills or hatcheries (Collett, 2013). Specific steps then are tailored to risks of specific parasite taxa introduction and spread appropriate to that zone. It is generally easier to prevent parasite invasion in somewhat more controlled circumstances, such as housing that excludes wild birds (e.g., sparrows) or mammals (e.g., rodents) that can potentially harbor and spread parasites to poultry. Free-range or pasture-based conditions can make biosecurity more difficult, while an enclosed, indoor system would be more amenable to stringent biosecurity measures. Something as simple as a roof can minimize exposure to parasites or pathogens that might be transmitted by fecal—oral pathways via wild birds flying overhead.

Another component of good biosecurity is the practice of not mixing ages of poultry, and depopulating entire flocks and then cleaning and disinfecting facilities thoroughly before bringing in a new group of birds. This helps to reduce parasite challenges to a new flock.

While on-farm eradication of a pest or parasite species is often desirable, it may not be practical, achievable, or sustainable. For certain damaging parasites, particularly if we are confident in our future ability to exclude them, it might be worth some serious effort. It may require total depopulation of birds as a first step. Cleaning, disinfection, sufficient host vacancy time (to allow parasites to die off), and removal of parasite-contaminated materials or substrates would follow. This is the best, though most extreme (and perhaps expensive), measure to give future flocks the opportunity to be parasite-free.

Parasites like northern fowl mites, on the other hand, travel well on wild birds and rodents, not to mention equipment, egg flats, or personnel (Kells and Surgeoner, 1997) or may persist at low levels chronically in an older flock. Both *Dermanyssus* and *Ornithonyssus* can persist quite well in the housing environment without live hosts for weeks to months (Chen and Mullens, 2008; Nordenfors et al., 1999), especially in areas that cannot readily be cleaned, such as tiny cracks in nest boxes. A crack of 0.5 mm in width (1/50 of an inch) is enough to harbor northern fowl mites, and a deep crack would resist wetting with a disinfection or pesticide spray. Mites thus will often find their way into clean bird flocks sooner or later, unless careful biosecurity and management are maintained.

From an economic perspective, parasite management rather than eradication often makes the most sense. Integrated pest management (IPM) is a foundational concept in agriculture (Axtell, 1986). All practical steps to prevent pests and parasites are taken, and when pests do appear in a flock they are controlled only when their populations are expected to cause significant economic damage compared to doing nothing. The economic threshold is the point where control must be implemented to prevent damage that would exceed the costs of that control (e.g., pesticide costs, equipment, and labor). This concept only works for pests that are at least tolerable at low populations. For example, host grooming might suppress some feather-feeding poultry lice, and minor feather damage may be inconsequential. Under normal conditions these low densities of lice probably have little or no economic impact and would not warrant the cost of control efforts. This concept potentially applies to endoparasites, but few thorough economic thresholds exist for them. Economic thresholds are more easily calculated or used for plant crops than for animal parasites, which famously can cause "hidden" losses to animals. Parasites sap host vitality or force the hosts to spend resources on things like immune responses, rather than devoting those resources to growth and/or reproduction, which can be nuanced and difficult to quantify (e.g., Murillo et al., 2016). Parasitized hens that are otherwise healthy might continue to lay plenty of eggs, for example, but require more feed to do that. This might be hidden economic damage unless feed is carefully monitored.

Animal welfare adds complexity that plant crop managers do not need to address. Even if a parasite is not causing demonstrable economic losses, poultry keepers may feel compelled to control that parasite anyway if it is thought to be reducing quality of life for the animals. In general this is not yet legally mandated, although that time could be coming.

One hallmark of IPM is that combinations of control measures (prevention, animal management, and judicious use of control materials) are used in concert in the most economical, timely, and effective way possible, based on a solid scientific foundation of knowledge of pest biology. Below we will discuss different types of management tactics.

14.5.2 The chemical control palette: Pesticides, repellents, and delivery methods

Here we include synthetic and natural chemical compounds with likely use for poultry pest control. Pesticides include a toxicant that kills the target pest, while repellents are deterrents which frequently are nonlethal. Currently used synthetic (man-made) pesticides are considerably safer than many materials used in the past, which were more directly toxic to vertebrates and caused more severe environmental (nontarget) effects. For example nicotine, a naturally occurring compound in plants, was formulated for use in poultry cages until the early 1980s. The material was routinely painted onto cage bottoms in a concentrated form (40% nicotine sulfate) for poultry ectoparasite control (Furman, 1953). We now know that nicotine at this concentration has an unacceptably high risk for people, comparable to some very toxic synthetic organophosphate insecticides that also are now mostly disallowed. The nicotine lower limit fatal to humans is only 6.5–13 mg/kg (oral) (Mayer, 2013), meaning that about 0.5 g of it (about 0.02 ounces) could potentially kill someone. In addition, broad-spectrum fly larvicides were once commonly sprayed on manure surfaces in caged layer poultry houses where manure was allowed to accumulate for months or longer. Topical larviciding has now mostly been curtailed or limited to spot treatments of wet areas. This is due to fly resistance development and devastating impacts on other arthropods in the manure community, including many desirable fly natural enemies like predaceous beetles or mites that could keep flies under substantial control (Wills et al., 1990).

Parasiticides that are legal for internal use in poultry may require a veterinarian's approval. They tend to be delivered in feed and/or water. Withdrawal periods (period between last use of a chemical and slaughter for meat or use of eggs) may apply. Regulations vary among countries; the US Food and Drug Administration maintains an Approved Animal Drug Products List (aka Green Sheet). Some selected and commonly used synthetic materials, sorted by class, include methylpiperazines such as piperazine, imidazothiozole derivatives such as thiabendazole, and certain antibiotics such as hygromycin B (for roundworms), or sulfonamides such as sulfamethazine and thiamine analogs such as amprolium (for coccidia). Very few products are registered for direct use on poultry, however, and using products in a way not described on the pesticide label ("off-label" or "extra-label" use) is complicated in the United States. Some categories of chemicals cannot be used legally off-label, while others may be prescribed by veterinarians even in an off-label use situation, along with careful record keeping (AVMA, 2017; FARAD, 2017). This places responsibility on the veterinarian with regard to aspects such as withdrawal times for food animal uses.

Pesticides effective against mites, lice, and other arthropods primarily act as nerve poisons, though they may have different modes of action (Casida, 2011). Some pesticides and parasiticides are readily available for environmental (off-animal) use without veterinary consultation.

Presently the most common pesticides for arthropods include natural pyrethrins, their synthetic analogs the pyrethroids (e.g., permethrin), and growth regulators such as hydroprene or methoprene. Insect growth regulators (IGRs) mimic or interfere with insect hormones or chitin synthesis (Merzendorfer, 2012), so they interfere with development, proper egg hatch, and molting between life stages. The IGRs thus tend to be relatively selective toward the target pest. Other pesticides applied externally (to birds) or more often to the environment (e.g., surface sprays) include organophosphates (e.g., phoxim), carbamates (e.g., propoxur), or sometimes macrocyclic lactones (e.g., ivermectin). There are also a number of insecticides specifically targeting flies in baits. These are toxicants mixed with sugar as granules and are eaten by flies, with a "bittering agent" (denatonium) to help prevent accidental ingestion by vertebrates (e.g., pets or children). Fly baits include several different insecticide classes, including neonicotinoids (imidicloprid), carbamates (methomyl), and anthranilic diamides (cyantraniliprole) (Murillo et al., 2014).

The pesticides listed above are generally synthetically made and would be of use only in conventional (nonorganic) settings, with the exception of natural pyrethrins, which are plant-derived. Other major groups of plant-derived materials (botanicals) have received attention, such as neem or plant essential oils. In some cases feeding plant products to infected hosts can suppress internal parasites, for example oregano oil can suppress *Eimeria* spp. in chickens (Tsinas et al., 2011). Muthamilselvan et al. (2016) provide a review of herbal remedies for poultry coccidia.

Many of the essential oils that may be useful for parasite control are aromatic compounds that can kill via direct contact or fumigation. Modes of action often are not established, but would include acting as poisons and interfering with physiology (e.g., nerve signaling or respiration), interfering with feeding, or causing other behavioral modifications to the parasites (George et al., 2014). Examples of essential oils are thyme, cade, clove, garlic, rosemary, peppermint, eucalyptus, citrus, and extracts from various grasses (George et al., 2010). They do have some drawbacks such as batch consistency and limited residual activity (usually < 24 hours) (George et al., 2014) and may be expensive or difficult to obtain. In some circumstances one or a few carefully timed applications might suffice, however, and persistence of some materials under "ideal" lab conditions can be longer, such as 14−30 days for thymol (Massoumi et al., 2016).

Most published data for essential oils are based on laboratory bioassays, but that is not equivalent to showing field efficacy. More field testing, particularly with proper controls and decent experimental replication, is needed on important targets such as *D. gallinae* or *M. domestica*. Notably, some of the botanicals are also probably useful as repellents. Direct contact may kill a pest, but residues in the environment or on a bird's body can repel them (Nechita et al., 2015). It is likely that some materials cause important sublethal effects such as reduced parasite feeding, fecundity, or lifespan, but this aspect has been mostly ignored by researchers to date.

Botanicals might readily be used in both organic and conventional settings (consult the OMRI listing for materials listed for unlimited organic use in the United States, for example). Botanical products frequently have not been as thoroughly scientifically tested for efficacy on pests as synthetic materials. This may be due to their more limited markets and general lack of major company backing. For certain parasite groups, such as coccidia, scientists have explored a variety of natural chemical products that might be fed to poultry, for example vitamins or probiotics meant to stimulate natural immunity (Abbas et al., 2014; Williams, 2005), though this area requires further study.

14.5.3 Resistance

Resistance to chemical compounds in parasites and insect pests may be encouraged by short generation times, intense or continuous selection for resistant phenotypes by use of a single compound, and/or the fact that often all animals are treated and the parasites therefore have no untreated "refugia" in which to maintain susceptible genes in the pest population (Georghiou, 1994). A textbook example of resistance development occurred with the fly larvicide cyromazine, used as a feed additive for house fly (*M. domestica*) control. With the chemical constantly in the food supply, the hen manure was continuously and completely treated. In this case, resistance began to show up on treated farms within about 2 years of first use; tripling the use rate from the initial 1.5 ppm to 5.0 ppm unsurprisingly did not solve the problem (Sheppard et al., 1992). A recent USA survey of helminths in commercial broiler breeders (Yazwinski et al., 2013) showed that more than 98% of birds were infested and that parasite loads often were in the range where the literature shows economic parameters such as feed conversion or weight gains are reduced. This was despite typical scheduled treatments with anthelmintic compounds. As the authors discuss, however, control failures can be complex and are not necessarily due to resistance per se. Rotating classes of materials (using different modes of action) is one of the best defenses against the development of resistant strains of microorganisms or arthropods (Georghiou, 1994). One can limit the need for chemical controls by incorporating several tactics into an IPM strategy which also can prolong the usefulness of such chemical or pharmaceutical products.

14.5.4 Nonchemical control approaches

Here we include inert materials, biological control, cultural control (housing design and flock management), and the potential for resistance breeding and vaccine development.

Inert materials like inert dusts such as kaolin (clay) or DE have the potential for use in either nonorganic or organic settings. They work by compromising the pest cuticle by abrasion and adsorption of the waxes that normally keep arthropods from drying out (Ebeling, 1971). While DE is promoted as a parasiticide for internal parasites such as coccidia or helminths, very little experimental evaluation has been done. Bennett et al. (2011) did test DE fed to naturally parasitized (free range) hen strains considered either parasite-susceptible or resistant, and helminth and coccidia loads tended to be less in the treated susceptible hens relative to susceptible hen controls. Hens infested later with northern fowl mites also seemed to have fewer mites after DE treatment, as determined by visual estimation.

Dusts such as DE have been tested several times for red mite (*Dermanyssus*) control in the laboratory (Kilpinen and Steenberg, 2009; Maurer et al., 2009; Steenberg and Kilpinen, 2014) and different formulations differ substantially in efficacy. We are aware of only one very small-scale field evaluation of DE for *Dermanyssus* control, however (Maurer and Perler, 2006). Unlike botanicals that evaporate or break down chemically, inert dusts like DE have the potential to persist for long periods of time. Dusts also may be used against *O. sylviarum* or body lice when placed in shallow boxes with a carrier such as sand. This takes advantage of the bird's natural propensity to dustbathe in fine materials (Olsson and Keeling, 2005) and allows them to self-treat (Murillo and Mullens, 2016b). The DE or kaolin does have to be concentrated in a box and recharged regularly (probably weekly), however. DE dislodged from the boxes by birds or even purposefully added to the litter may be noticeable visually in the environment. Such DE is insufficient to reduce northern fowl mites or chicken body lice, however, even though hens do dust bathe in litter outside of the boxes (Martin and Mullens, 2012; Murillo and Mullens, 2016b). Although the litter or manure particles in dustbathing areas in confined poultry housing may seem powdery to us, they are apparently not fine enough to adhere to arthropod cuticles or result in control. Sand alone in a dustbox has no effect on *O. sylviarum* (Vezzoli et al., 2015). Dustbox self-treatment would be more difficult to implement in cages, even larger enriched ones, although it may be possible. Dustbox use with DE has been shown to suppress *Ornithonyssus* and body lice significantly in poultry, but generally does not eradicate the pests. It is interesting that some birds, maybe up to 20%−30% in a cage-free setting (e.g., Martin and Mullens, 2012), do not use dustboxes regularly, which allows them to remain heavily infested. In semi-field studies (Martin and Mullens, 2012; Murillo and Mullens, 2016b) one dustbox was used per small flock of 12 or 18 birds, respectively. Finding ways to make the dustboxes more attractive and optimizing the number and size of dustboxes for commercial-scale flocks requires more research, but is a logical next step.

Sulfur dust is a chemical but is included here because of potential similarities in use to DE. Dustboxes can also be used to deliver sulfur dust, which is a particularly potent acaricide (mites) and impacts lice as well (Martin and Mullens, 2012). Sulfur is active at remarkably low levels; less than a gram on a chicken can eliminate *Ornithonyssus* populations (Mullens et al., 2012; Murillo and Mullens, 2016c). Microorganisms on the bird's skin apparently break down the sulfur, and hydrogen sulfide in the feather coat then essentially fumigates the mites. Sulfur dust combined with sand in dustboxes can eliminate *Ornithonyssus* even on birds in that flock that do not use the dustboxes (Martin and Mullens, 2012). So, unlike DE or kaolin, sulfur might be effective even at low concentrations in the environment, for example as a litter treatment, but this has not been specifically tested to our knowledge.

Biological control uses pest natural enemies, including predators, parasites, and pathogens, to reduce pest populations. In the future we might add competitors to that list, in that it might be possible to use or encourage relatively less pathogenic organisms to suppress more pathogenic ones. This might occur either through direct competition for host resources in the body or through indirect interactions with the immune system, akin to vaccinating with a less pathogenic parasite strain. For example, while the mechanism of exclusion is not yet known, chicken body lice (*M. stramineus*) severely reduce or eliminate northern fowl mites on the same beak-trimmed bird (Chen et al., 2011). This is beneficial because the mites are more damaging to production, survive much better in the environment, and are harder to control chemically than the lice. While lice themselves are of course undesirable, it is conceivable that the lice could be used strategically to eradicate mites from a flock (e.g., late in its life), followed by louse eradication chemically or via bird depopulation. This has not been tested at a commercial scale. One also can appreciate that convincing a poultry producer to introduce one troublesome parasite to control an even more serious one is hardly easy.

Little is known about biological control for internal parasites (e.g., Thamsborg et al., 1999). Internal parasites likely have few multicellular parasites of their own, and there are even fewer predatory organisms capable of functioning in the inhospitable vertebrate intestinal tract. Parasite stages outside the vertebrate body are susceptible to natural enemies (Larsen, 1999), such as fungi which produce chitinases affecting nematode eggs in soil (Gortari and Hours, 2008). Environmental pests like larval house flies might be suppressed by birds feeding upon them. The bacterial agent *Bacillus thuringiensis* will kill fly larvae if applied to manure (Mwanburi et al., 2011). While we are not aware of them being tested on poultry nematodes specifically, the individual crystal proteins of *B. thuringiensis* do seem to have broad activity against internal helminths (Hu and Aroian, 2012).

Like other animals, multicellular internal parasites probably have a group of microbial associates (microbiota), some of which are required for survival. While currently little is known about parasite microbiota, in the future it might be possible to develop a control method that kills or otherwise compromises the parasites' own vital microorganisms. Some human filarial nematode parasites (*Brugia* spp., *Onchocerca* spp.) have an obligate endosymbiont, *Wolbachia* (Saint André et al., 2002; Taylor et al., 2013). Treatment of the human host with doxycycline (an antibiotic) kills the *Wolbachia*, which in turn causes death of the nematode. It is unknown if other symbionts may inhabit other groups of vertebrate nematodes and show similar promise for control, but research may provide some answers.

Traditional biological control has the potential for the management of some ectoparasites and environmental pests. *Dermanyssus* (red mites), for example, live in wild bird nests as well as chicken houses. In the wild they are subject to severe predation by other mites, and these predators could be introduced into domestic poultry settings to control red mites (Lesna et al., 2012). In Europe, predatory mites for *Dermanyssus* control have been commercialized, but realistic field efficacy tests are still lacking (Sparagano et al., 2014).

Pathogens also have a lot of potential to reduce poultry pest numbers, especially in the environment for temporary pests. Fungi in the genera *Beauveria* and *Metarhizium* are readily produced commercially and have broad host ranges for poultry pests (see Oliveira et al., 2014). They have considerable promise for house fly control when applied to poultry house walls where flies rest (Acharya et al., 2015; Kaufman et al., 2005). Both fungi have been explored for suppression of the habitat-dwelling mite *D. gallinae* (Steenberg and Kilpinen, 2003; Tavassoli et al., 2008). *Beauveria* has been tested for permanent ectoparasites like northern fowl mites or lice, although with mixed results (Mullens et al., 2012; Oliveira et al., 2014). The warmth of a bird's body ($>30°C$) tends to reduce the efficacy of commercially available broad-spectrum fungi such as *Beauveria* for on-bird use (Oliveira et al., 2014). There may well be important bacterial, protozoan, or viral pathogens that are effective, but remarkably few studies have been conducted even to survey for them in the field. Such surveys would be a fruitful area for future research.

Pest flies are susceptible to a number of small wasp parasitoids that attack their pupal or sometimes larval stages, and insectary-reared parasitoids can suppress house flies, especially when the parasitoids are released in confined spaces such as poultry houses (Geden and Hogsette, 2006). Similarly, several significant beetle and mite predators eat immature flies (Archiano and Giliomee, 2006). These predators occur naturally and it is good to preserve/encourage them in the habitat (Mullens et al., 1996). Going forward, introductions of arthropods that prey on flies may be possible in some systems, although in general arthropod predators can be very difficult to produce commercially.

Cultural control of parasites via use of pest-resistant housing design or specific management tactics has a lot of potential. Here it is critical to understand the entire life cycle of the target pest(s). We have already discussed above how conventional cages, although they are severely lacking with respect to behavioral aspects of welfare, do at least suppress or prevent a lot of parasite groups. All other housing types, from enriched cages for laying hens to free range or pastured environments for poultry generally, supply critical habitat to parasites in one of two primary ways. First, they supply harborage (cracks and crevices for hiding) near the birds. Second, they supply substrate (e.g., moist, organic soil) that creates the possibility for fecal−oral contact and that is necessary for completion of the parasite life cycle or the presence of intermediate hosts.

How might one alter this situation to disfavor parasites? In general, moderately warm (20−30°C) and moist conditions are good for parasites. Examples include *Eimeria* oocysts, nematode eggs, or immature sticktight fleas. Drier substrate or bedding, floor heating, and well-drained soil are better for birds and also help discourage parasites and reduce other pathological conditions such as foot pad dermatitis (Abd El-Wahab et al., 2012). Large or long-term accumulations of moist feces, or organic substrates such as spilled feed, allow significant fly or beetle development. Bedding material choice (ideally one that is not absorbent so it will not hold moisture) is also important. Regular checking for water leaks from water lines or evaporative cooling misters is also helpful. Protecting the soil from direct wetting by use of a roof also helps if it is feasible or allowed. Removal of substrate, especially feces, is beneficial, and timing may be important for fly control (Mullens et al., 1996). For pest flies, the removal of substrate at regular intervals of a few days, even in summer when they develop faster, usually will prevent the fly larvae from successfully pupating. Composting waste potentially creates a valuable product and involves temperatures high enough to kill most pests and parasites (Pitts et al., 1998), but also requires carbon amendments, moisture control, periodic mechanical turnover, and is somewhat tricky to perform successfully. Removing manure can also directly remove oocysts, eggs, or other parasitic life forms from the environment. The substrate can be taken off-site or, in dry climates, spread thinly (less than 5 cm depth) to be dried by the sun. Most flies require moisture levels above 60% for larval survival or 70%−80% for oviposition (Stafford and Bay, 1987). Maximizing air flow in a facility also can reduce moisture buildup. Manure belts should be able to be easily cleaned, and good aeration across the belt systems can begin the feces drying process.

Housing should be designed with the idea of denying parasites harborage, especially near the bird roosting areas. Such pests like to be wedged into cracks and crevices that just fit their bodies. Red mites (*Dermanyssus*) thus prefer cracks and crevices of 1−2 mm (Sparagano et al., 2014), while bedbugs (*Cimex*) or soft ticks (*Argas*) would inhabit larger openings (3−5 mm depending on life stage). Good joint fits help prevent harborage, and some construction materials (metal, plastic) are much easier to fit tightly and to clean and disinfect between flocks. Where cracks or crevices cannot be minimized in existing construction, it may still be possible to introduce inert dusts such as DE to make the harborage less hospitable for resting parasites. Because *Dermanyssus* has become such a severe pest in Europe, an interesting variety of other approaches tailored to that mite has been examined. These include altering light schedules (mites like to feed during prolonged periods of darkness) or heat treating empty poultry houses (to about 45°C) to kill or stress the mites (Mul et al., 2009).

Host defenses can be effective because the main natural enemy for internal and external parasites is the vertebrate host itself. Host grooming is an early line of defense already mentioned for reducing ectoparasites like mites or lice. Wild birds have a number of other interesting behaviors, including sun basking or anointing themselves with natural materials such as aromatic plants or crushed ants, possibly to combat ectoparasites (Clayton et al., 2010). A few of those behaviors ultimately might have some use in domestic bird systems as well, or lead us to useful chemicals for pest control, but much more experimental work is needed to prove their utility. Beak trimming is a common practice performed by commercial poultry producers. It is desirable for many lines of chickens to curtail cannibalism and feed waste, but the trimming greatly enhances susceptibility to northern fowl mites and lice through impaired grooming (Chen et al., 2011). Exceptionally docile lines, such as Hy-Line's White Leghorn line CV20 (aka W36), conceivably might be kept without beak trimming, at least in some housing systems, allowing them to effectively groom ectoparasites and reduce or perhaps eliminate the need for chemical control (Chen et al., 2011).

Host diet could ultimately influence parasite infection or performance through a variety of routes, although these mechanisms are perhaps indirect. For example, supplemental lysine in the diet of chickens infected with *Ascaridia* reduced the incidence of infection (perhaps via stimulation of the immune system) but not parasite fitness (Das et al., 2010).

Bird genetics certainly influence susceptibility to parasites (Miller and Taylor, 2016). Breeding for resistance to one parasite, however, may not confer resistance to another. This illustrates that activation or effectiveness of the different host resistance mechanisms (inflammation, involvement of different defensive cell types) likely varies substantially from one parasite to another. While host strain susceptibility differences have been known for some time, we only recently have been able to understand the genetic foundations of resistance to parasites. Thus, while commercial poultry breeders presently focus more on production traits, it is quite likely and exciting that breeding for parasite resistance simultaneously with other desirable traits may become feasible in the future. The Major Histocompatibility Complex (MHC) genes impart parasite and pathogen resistance, and have been particularly studied over the past 10−15 years, including investigations on their role in defending against *Eimeria* spp., *Ascaridia*, and *O. sylviarum* (Miller and Taylor, 2016).

The idea of parasite vaccines is interwoven with the idea of breeding for resistance. This is an attractive concept that seems more promising for certain groups of parasites. Live vaccines have been available commercially and used against *Eimeria* spp. for many years, and such a tool might be one of the few management options organic producers have for coccidia suppression. Modern molecular biology offers enhanced understanding of parasites that may pay off in improved control. For example, a new protective protein in *E. tenella*, EtIMP1-flagellin, can be produced in bacterial cell culture and can significantly synergize vaccines (Yin et al., 2013). DNA vaccines have a number of potential advantages, including the fact that reversion to pathogenicity (as might occur with an attenuated but live vaccine organism) is not possible. Poultry DNA vaccines, including for *Eimeria* spp., have been reviewed recently by Meunier et al. (2016).

For external blood-feeding parasites the prognosis is less optimistic, but the potential for vaccines is still intriguing. Infested White Leghorn layers generally develop good resistance to northern fowl mites. This can reduce mite numbers by over two orders of magnitude over several weeks' time, but will not eliminate them entirely (Mullens et al., 2009; Owen et al., 2008). *Dermanyssus* antigens have been identified and tested with the idea of developing a recombinant red mite vaccine (Bartley et al., 2015; Wright et al., 2016).

With regard to vaccines or host resistance, several important aspects deserve mention. Immune responses are quite complex and variable over time. They typically have not evolved for protection against a single parasite. Instead, responses have developed over evolutionary time to address a wide and unpredictable array of perhaps hundreds of potential targets, from viruses to ticks. As the immune response mobilizes, physiological costs probably are also incurred by the host. The resources for a bird to fight a parasite via immune responses might otherwise be used for normal body functions that are of value in commercial production, such as growth (weight gain) or reproduction (egg production). So, while host resistance sounds like an attractive option, it is possible that the resistance might actually come at a rather high economic cost (e.g., feeding birds much more in order for them to fight the parasites). In that case, birds that tolerate parasites without mounting a marked immune response might actually be more cost-effective. Although this has been explored in a preliminary way for *Ornithonyssus* (Murillo et al., 2016), this area of scientific inquiry is still in its infancy.

14.6 Balancing welfare concerns and pest damage with economics

The domestic chicken is one of the most important food animals in the world (Vaarst et al., 2015). Probably billions of people globally benefit from poultry meat and eggs as very high protein foods. It is important, therefore, to try to keep these foods accessible to poorer people around the world, including the sometimes-overlooked people of limited means within the developed countries. It is remarkably easy for much of the public, including professionals or politicians who make the decisions, to lose sight of the fact that production-scale agriculture must be profitable. Solutions to address bird welfare concerns and parasite control must not only take bird comfort into account, they also need to make economic sense and preserve the idea of producing food on a scale sufficient to feed large numbers of people.

That said, current poultry production systems, including newer housing systems for laying hens, should be able to meet those needs. Many, and perhaps most, parasites should be amenable to integrated management, which we need to match to the production system and pest involved. Sometimes this will hinge on knowledge of a critical parasite or pest life history aspect we can exploit. Parasite control will require using a variety of housing-specific management techniques, as discussed earlier in this chapter. Economically, however, the array of techniques and their use will need to "pay off" for a poultry producer in the short and/or long term. The expenses of complete pest eradication might be very high short-term. For example, it would be immensely expensive to eliminate all birds from a facility, disinfest housing and substrates, wait long enough for the parasite to die off, and then implement careful future biosecurity steps to prevent reinvasion of a parasite. The facility has no income for a period of time, but those expenses could more than pay for themselves over time in the long run, because a farmer no longer has to manage that pest, or contend with its damage to bird welfare and production.

It is useful to consider the timing of parasite damage as well. Northern fowl mites are a good illustration. The mites do not tolerate high environmental temperatures well, so are less likely to be a pest in warmer weather. They reduce egg production and feed conversion efficiency during the first egg production cycle but, once immune, hens probably will not experience that level of damage again (Mullens et al., 2009). So the flocks at highest risk are those coming into peak egg production for the first time (25−35 weeks of age) in cool weather. Knowing this pattern, a knowledgeable producer could implement mite monitoring on hens in the flock as soon as the new flock is placed in the laying house (e.g., at 17−19 weeks of age), especially if the facility has a history of mite problems. Treating heavily infested birds is far less effective than treating lightly infested ones (Mullens et al., 2009). The goal is to treat at the right time, for example when 25% of the hens have any mites. This is done by proceeding through a house and checking hens until a decision point is reached (presence−absence sequential sampling as per Harris et al., 2000). Multiple treatments might be required, but the goal would be to avoid the high level of short-term damage expected without any intervention. Each parasite's life history and damage potential, and the management tools available in that production system, should be carefully considered for their potential to enhance bird welfare and simultaneously to return profit for the producer.

14.7 Conclusions and implications

Changes in poultry production are being driven by animal welfare considerations. Housing and management greatly influence the prevalence and intensity of parasites, so parasite management must be a part of the conversation as we propose or adopt production system changes. Relative to conventional cages, more complex housing systems for laying hens (enriched cages to cage-free to free-range) generally benefit parasites to varying degrees. They do this by (1) increasing near-host harborage for parasites, (2) allowing more fecal contact and thus fecal−oral parasite transmission, (3) providing soil contact for parasite off-host life stages and habitat for parasite intermediate hosts, and/or (4) increasing the numbers of birds that interact (size of the host pool). While some parasites such as *O. sylviarum* thrive regardless of housing type, others like *D. gallinae* are already present in the United States and are likely to increase in USA poultry operations as conventional cages are phased out. Resurgence of *Dermanyssus* has been clearly documented in Europe as a consequence of poultry production changes similar to those being implemented or considered in the United States. We therefore need to be proactive in biosecurity, in developing parasite and pest detection and monitoring techniques, and in providing integrated management methods that will work in these systems. In the past we have been able to use synthetic chemicals as the mainstay of control for many parasites. This will not be possible in organic systems and may be more challenging to apply in any alterative production systems. While we reviewed a number of approaches or control ideas, many of these are simply too early in development or are not currently supported by sufficient research to allow their recommendation or use. Utilizing a diverse suite of techniques probably will be required to achieve economical, sustainable, and effective parasite control and to keep future poultry flocks healthy.

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Using genetic approaches to improve host responses to environmental stressors

15

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15.1 Introduction

There are many environmental stressors that can affect poultry well-being. In general, these stressors can be classified as biotic and abiotic. Biotic factors include bacteria, viruses, parasites, and fungi, while abiotic factors include heat stress, air quality, litter quality, and ventilation. Intensive genetic selection for either higher meat or egg production in past decades has resulted in chickens being more susceptible to environmental stressors, especially in intensive rearing systems. The physiological changes associated with selection for economically important traits such as growth rate, egg production, and feed efficiency have had significant negative impacts on the welfare of both broilers and layers. Pathogens and shifts in temperature are two of the most important environmental stressors affecting poultry welfare, and these stressors also cause significant economic losses in poultry production.

There are several potentially effective approaches for mitigating the negative impacts of these stressors on poultry welfare, including improvements in basic husbandry and diet, as well as genetic selection. With recent developments in biotechnology and sequencing technologies and significant cost reduction in next generation sequencing, advanced genetic and genomic techniques offer promising approaches for addressing these challenges. This chapter will discuss several major viral and bacterial diseases and heat stress in poultry, focusing on the current progress in the genetic improvement of resistance to these stressors.

15.2 Biotic stress—Viral diseases

15.2.1 Avian influenza virus

15.2.1.1 Background

Influenza viruses belong to the *Orthomyxoviridae* family (Acheson, 2000). There are five different genera in this family, including influenza A, B, C, Thogotovirus,

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and Isavirus (Sebbag, 2005). Influenza A viruses (AIVs) can infect avian and mammalian species (Stephenson and Democratis, 2005). As zoonotic viral pathogens, AIVs pose a serious threat to poultry production as well as human health. Since 2003, 850 laboratory-confirmed cases of human infection with H5N1 highly pathogenic avian influenza (HPAI) have been reported (World Health Organization, 2016). In addition, H7N9 low pathogenic AI (LPAI) viruses have caused more than 600 serious human illnesses in China since 2013 (Lam et al., 2015). From 1997 to 2016, multiple outbreaks of HPAI (H5) viruses were reported in commercial poultry in North America, including a H5N2 outbreak affecting a flock of 7000 chickens in Texas in 2004 and H5 outbreaks across 21 states from 2014 to 2015 (Centers for Disease Control and Prevention [CDC], 2016; Pelzel et al., 2006). In January 2016, a H7N8 HPAI outbreak was reported in nine commercial turkey flocks in Indiana. To date, the AIV outbreaks occurring in the United States in 2014 and 2015 are the most severe epizootic events in the poultry industry. They affected 42.1 million layers and pullets as well as 7.5 million turkeys (Windhorst, 2015). In Iowa alone, the total cost to the economy was estimated at almost $1.2 billion (Windhorst, 2015). The impacts of these and other AIV outbreaks illustrate the need for a better understanding of chicken immune response mechanisms against viral infection. Elucidating these mechanisms will allow for the development of novel therapeutics in the control of AIVs in chickens and strategies to protect humans against new AIV spill-overs from birds (Goossens et al., 2013).

15.2.1.2 Ecology of influenza A viruses

Avian influenza viruses are divided into different subtypes based on differences in their hemagglutinin (HA) and/or neuraminidase (NA) proteins. At this time, 18 subtypes of HA (H1−H18) and 11 subtypes of NA (N1−N11) have been identified, with several combinations of HA and NA found in various host species (http://www.cdc.gov/flu/about/viruses/types.htm, CDC, 2016). The main natural reservoirs of AIVs are wild waterfowl and shorebirds, which are thought to be the source of influenza A viruses in all other animals (Knipe et al., 2007; Webster et al., 1992). While AIVs frequently infect nonnatural hosts such as chickens, pigs, and humans and cause mild self-limiting infections (Ma et al., 2007), the genetic variability of AIVs leads to the generation of new virus strains that can cause severe disease and pandemics (Acheson, 2000).

Depending on their pathogenicity, AIVs are classified as low pathogenic (LP) or highly pathogenic (HP) (Jackson et al., 2009). HPAIVs can cause clinical disease, with up to 100% mortality during some outbreaks in susceptible poultry species (Alexander, 2000). Although only H5 and H7 subtype viruses have been classified as HPAIV, not all H5 and H7 subtypes are HP (Alexander, 2000; Brahmakshatriya, 2009). Infection with LPAIV strains in poultry can cause asymptomatic to mild respiratory and gastrointestinal tract infections, followed by a reduction in egg production. They can also lead to secondary bacterial infections (Acheson, 2000). Although infections with H5 and H7 subtypes of LPAIVs cause only mild clinical signs, these viruses are important as they are capable of mutating to HPAIVs

(Acheson, 2000; Brahmakshatriya, 2009; Leijon et al., 2011). While most investigations have focused on HPAI viruses, LPAI viruses are increasingly receiving more attention.

15.2.1.3 Host immune responses during avian influenza virus infection

AIVs cause infection by invading and replicating within host cells. During their life cycles, they have a relatively short extracellular period and a longer intracellular period, during which they undergo replication (Knipe et al., 2007). The host immune system has mechanisms that target viruses during both phases of their life cycle, and that involve both innate and adaptive immune responses (Abbas et al., 2013). Influenza viruses code for the nonstructural protein NS1, which allows them to inhibit host innate immunity and infect the host (Knipe et al., 2007). However, once the infection is initiated, the adaptive immune response is stimulated and the cellular immunity is activated. Viral clearance can only be achieved through adaptive immunity (Yang, 2009).

15.2.1.4 Transcriptome analysis to understand host response to AIV infection

The responses of host cells to pathogenic microorganisms are the major focus of host−pathogen interactions. Pathogen-induced phenotypic changes in host cells are always accompanied by remarkable changes in gene expression (Jenner and Young, 2005). Understanding the gene expression profile at the global level is key to gaining insight into cellular functions associated with the interaction between hosts and viruses. There are thousands of genes targeted by viruses and other pathogens in many cell types that participate in the mediation of inflammation, response to interferon, and activation or attenuation of immune responses (Jenner and Young, 2005). The profiles of genome-wide sets of genetic variants in terms of alterations in response to specific biological stimuli provide valuable insights into interpreting functional elements of the genome and revealing the molecular constituents of cells, and for understanding developmental and disease processes. Therefore high-throughput transcriptome profiling technologies such as next generation sequencing are needed to carry out these types of studies. By using this powerful tool, potential candidate genes or candidate microRNAs (miRNA) that regulate genes influencing host immune responses can be identified more efficiently.

Historically, identification of small noncoding RNA has been performed by computational prediction, real-time quantitative polymerase chain reaction (PCR), and sequencing the bacterial cloning cDNA libraries (Gu et al., 2007; Xu et al., 2006). With the advanced development of next generation sequencing, there is now superior sensitivity at higher coverage of the transcriptome, particularly in discovering those miRNAs with low abundance as well as novel miRNAs that cannot be identified using traditional cloning approaches. Small RNA deep sequencing has been widely used to profile miRNAs, including both chicken miRNAs and Marek's disease virus miRNAs (Burnside et al., 2008; Glazov et al., 2008; Wang et al., 2009, 2012).

RNA-seq is a powerful sequencing-based method that enables us to identify, profile, and quantify RNA transcripts across the entire transcriptome. Studies using this technology have already changed our views regarding the extent and complexity of transcriptomes in an organism and improved our understanding of the transcriptome (Wang et al., 2011). It provides great potential to analyze a variety of RNA variations that are important in regulating biological processes, including novel transcripts, novel isoforms, alternative splice sites, rare transcripts, and single nucleotide polymorphisms in coding regions, in a single experiment.

RNA-seq has been used in a variety of studies on host and AIV interactions. Changes in global gene expression in chicken lungs infected with AIV have been profiled via microarray analysis (broilers) (Wang et al., 2012) and RNA-seq analysis (layers) (Wang et al., 2014). In the layer study, two genetically distinct highly inbred chicken lines (Leghorn and Fayoumi lines) were used to examine resistance to LPAIV infection. Resistance was quantified by tracheal AIV titer, real-time PCR results to measure the expression of resistance-specific genes, and by lung and trachea lesion scores. Viral titration results indicated that the Leghorn line is more susceptible to AIV infection than the Fayoumi line. RNA-seq analysis of lung tissue collected at 4 days postinfection, the time at which lesion counts peak in the lung, revealed that only 198 genes were differentially expressed between Fayoumi and Leghorn birds (Wang et al., 2014). Transcriptome analysis by RNA-seq allows for further investigation of the genetic factors that contribute to increased resistance to AIV in chickens. A better understanding of these differentially expressed genes will provide critical information on the pathways and gene networks which will help to increase disease resistance in poultry.

15.2.1.5 Producing AIV-resistant chickens using transgenic approaches

Transgenic technology has been used to increase disease resistance in animals (Hunter et al., 2005). In 2011, a team of scientists in the United Kingdom developed transgenic chickens that showed limited transmission of AIVs to other birds (Lyall et al., 2011). The researchers introduced a lentiviral transgene into early-stage chicken embryos and generated one transgenic rooster and his progeny. The transgene expresses a small RNA molecule that matches the highly conserved sequence of an enzyme binding site on the influenza A virus genome. This small RNA molecule can impede the influenza virus replication by acting as a decoy for the viral polymerase, thus diverting this crucial enzyme during the process of replication. The researchers challenged the transgenic birds with H5N1 and housed them with uninfected birds. Although the decoy RNA did not prevent the infected transgenic birds from dying within days of exposure, it did prevent them from transmitting the influenza virus to any of the uninfected birds with which they were housed in direct contact. This study has provided the proof-of-concept that transgenic technology can be utilized during breeding to enhance disease resistance in bird populations, although commercial adoption of this method could meet with challenges due to the economic, political, and technical hurdles associated with genetically modified food animals. Rapid advances in transgenic technology have also enabled precise genome editing in chickens and other food animals, allowing for minor edits to the genes responsible for the resistant phenotype in a single generation without leaving any trace of foreign genetic materials (Dimitrov et al., 2016; Oishi et al., 2016; Park et al., 2014).

15.2.2 Newcastle disease virus

15.2.2.1 Background

Newcastle disease virus (NDV) is a variant of avian paramyxovirus 1 and is a negative-sense single-stranded RNA virus belonging to the genus *Avulavirus* in the family Paramyxoviridae. There are several different strains of the virus, each defined by its pathogenicity. They are grouped as velogenic (highly virulent), mesogenic (intermediate virulence), lentogenic (nonvirulent), or asymptomatic. Velogenic strains can manifest as two forms, neurotropic and viscerotropic. The neurotropic form is associated with respiratory and neurological symptoms, while the viscerotropic form results in severe hemorrhagic intestinal lesions. NDV infects a wide range of wild avian species and can infect birds asymptomatically. Transmission occurs through inhalation or ingestion of viral particles shed through both fecal matter and respiratory excretions. Symptoms of infection range from coughing and rales, to diarrhea and decreased feed intake leading to production losses (Beard and Hanson, 1984).

Chickens are particularly at risk of NDV infection, with outbreaks resulting in a 90%−100% annual mortality rate that can lead to devastating financial hardships for both large- and small-scale farmers (Alexander, 2001). It is particularly prevalent in poultry flocks in developing countries such as those in Africa and Southeast Asia. The economic impact of NDV outbreaks in these countries can be profound, as restrictions on trade can result in huge economic losses (Spickler, 2016a,b). Developing nations also face additional challenges during disease outbreaks due to dramatic environmental effects brought upon by climate change. Factors such as heat stress or severe drought can dampen the immune response and provide an additional stress factor that results in an increase in disease susceptibility. In the United States, two major outbreaks of NDV in 1971 and 2002 resulted in national animal health emergencies that devastated huge numbers of exposed poultry flocks. The estimated operational cost to taxpayers was approximately $56 million in 1971 and $160 million dollars in 2002, and resulted in millions of birds being destroyed to eradicate the epidemic (Spickler, 2016a,b).

Currently, vaccines are one of the primary methods used for NDV prevention. Unfortunately, infrastructure to support proper vaccination is still lacking in many regions, especially in developing countries where logistical and manufacturing issues are still unresolved (Kitalyi, 1998). Thus the agricultural community has been evaluating genetic improvement as a means to complement vaccination in production birds. The influence of host genetic background on NDV resistance has been well documented through studies showing that there are differential mortality rates among different chicken genetic lines (Hassan et al., 2004; Kaufman et al., 1999; Tsai et al., 1992) suggesting that genetic improvement can be an effective complement to vaccination for disease prevention (Lamont, 1998). Studies have shown that selecting for specific major histocompatibility (MHC) haplotypes in chickens can lead to reduced mortality rates and increased immune cell production in response to infection (Dunnington et al., 1992; Gehad et al., 1999; Zhou and Lamont, 2003).

Researchers in the USAID Feed the Future Innovation Lab for Genomics to Improve Poultry program (http://gip.ucdavis.edu) are utilizing advanced genetic and genomic tools to discover unique genes and genetic pathways that may be playing a role in host resistance to NDV during heat stress. Whole-genome expression analysis has allowed researchers to effectively profile the host immune response during pathogen invasion. Activation and inhibition of pathways such as interferon- β and interferon- α, which play critical roles in regulating the host innate immune response, can be observed within the context of the overall gene expression response of the host and inform researchers about the complex interplay of these immune pathways and how they are responding during infection (Park et al., 2014). RNA-seq analysis of two inbred genetic lines identified differential gene expression of toll-like receptor 3 and toll-like receptor 7 between the two genetic lines, which correlated with increased gene expression and decreasing viral load. As these two genes are major receptors within the innate immune response of the host, they are prime candidates for further functional analysis to confirm that there is genetic variation conferring host−pathogen resistance (Koma et al., 2013). Further comprehensive assessment of the molecular response to pathogen infection is critical to understanding the complex interactions between the genetic loci of the hosts and their environment.

15.2.2.2 Genome-wide association studies

Major technological advances in sequencing and genotyping methods have generated a tremendous number of studies identifying associations between single nucleotide polymorphisms (SNPs) and disease phenotypes. Microarray-based genotyping panels have allowed researchers to profile tens of thousands to hundreds of thousands of SNPs simultaneously from single individuals for genome-wide association (GWAS) or quantitative trait loci (QTL) studies. The principles of these studies are that there are many genetic variants in a population, and that some of these variants cosegregate with the causative SNP or allele that controls the phenotype. The flowchart to describe general steps of GWAS is presented in Fig. 15.1. Research that attempts to correlate the presence of specific SNPs with a specific phenotypic trait can lead to the identification of the regions that may be harboring the causative SNP and thus lead to the identification of the causative genetic variations. These studies have assisted in identifying causative genetic variants for over 200 disease traits among 1300 loci in humans (Cooper and Shendure, 2011).

In chickens, similar studies have been carried out to identify genetic variants involved in the increased production of antibodies against viruses such as Marek's

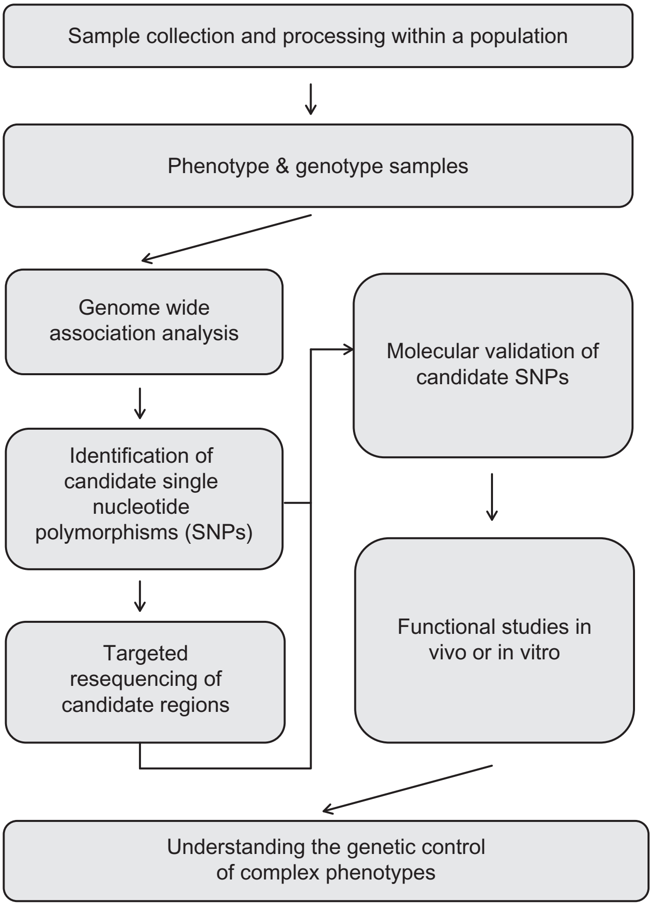

Figure 15.1 Flowchart of general steps to conduct genome-wide association studies. To provide enough statistical power to detect genetic effects, DNA is collected from a large number of individuals in a well-chosen population with the specific phenotype(s) of interest. The DNA is genotyped, usually using a high-density single nucleotide polymorphism (SNP) panel. Associations between SNPs and phenotype(s) are then analyzed to identify candidate SNPs or genomic regions that control the complex phenotype(s) of interest. Further functional studies focusing on candidate SNPs or regions can be conducted in order to elucidate the molecular mechanisms of genetic control of complex phenotypes.

disease virus and NDV (Li et al., 2013; Luo et al., 2013). Luo et al. (2013) identified a 100 Mb region on chromosome 1 that demonstrated a strong effect on the antibody response to NDV in chickens. Candidate genes such as *ROBO1* and *ROBO2* were in significant linkage-disequilibrium with the candidate SNPs identified in the study and have shown up in other GWAS involving antibody-mediated response to viral infection in chickens. Variant identification has been hugely improved through advances in genotyping technologies and an unprecedented number of discoveries are being made linking causal variants to phenotypes. In cattle, researchers are using

GWAS to identify SNP markers to construct haplotype blocks, or regions with co-occurring SNPs, to improve foreshank weight and triglyceride levels (Wu et al., 2014). These haplotype blocks can now be selected by breeders to improve the quality of key carcass trait components and act as markers for improved breeding programs. These advances pave the way to further our understanding of the genetic control of resistance to many poultry diseases that have previously gone unstudied.

15.3 Biotic stress—Bacterial diseases

15.3.1 *Salmonella enteritidis*

15.3.1.1 Introduction

Salmonella is rod-shaped, gram-negative enterobacterium that has an ability to colonize a wide range of hosts. Disease outcome in the host is dependent on the bacteria serovar, inoculation dosage, and host immune status (Griffin and McSorley, 2011). The genus *Salmonella* is divided into two main species, *S. bongori* and *S. enterica*. These species are then further classified into several subspecies, with more than 2500 serovars identified (Foley et al., 2013).

In poultry, salmonellosis can be classified more simply into two main types of infection, with either poultry-adapted strains or nonhost specific strains (Wigley, 2014). *Salmonella* Gallinarum and *Salmonella* Pullorum are host-adapted strains that cause fowl typhoid and Pullorum disease respectively, with high morbidity and mortality in avian species (Guard-Petter, 2001; Proux et al., 2002; Shivaprasad, 2000; Wigley, 2014). Because these strains are host-specific, they pose a minimal threat to human health and have been mostly eradicated from the commercial poultry industry in developed countries (Shivaprasad, 2000). However, the persistence of broad-host range strains like *Salmonella enteritidis* (SE) in chickens is a major concern for food safety and public health due to their ability to cause disease in humans. Poultry serve as a main reservoir of infection for humans, and consumption of contaminated egg and poultry products has resulted in outbreaks of food-borne illness worldwide (Andino and Hanning, 2015; Antunes et al., 2015; Gantois et al., 2009). Silent infections in chickens, broad-host range colonization, and high zoonotic potential are the major characteristics associated with SE that make eradication of the pathogen highly challenging.

15.3.1.2 Host phenotypic response

Except newly hatched or immunocompromised, chicks do not exhibit clinical symptoms of SE infection. Instead, the pathogen is able to successfully colonize the gut while the host is an asymptotic carrier shedding the pathogen periodically into the environment, leading to horizontal transmission. Vertical transmission of the pathogen from the hen to the developing egg occurs when the bacteria are able to colonize the reproductive tract and the yolk, albumen, and eggshell membranes become contaminated (Gantois et al., 2009). SE infection in young chicks often results in diarrhea and high mortality. Additionally, postmortem findings often indicate inflammation of the caecum.

SE susceptibility in chickens is determined by bacteria load recovered from organs like the ceca, spleen, and liver (Calenge et al., 2010; Desmidt et al., 1997). In contrast, SE infection in humans is characterized by the presence of clinical symptoms like diarrhea, nausea, vomiting, abdominal cramps, and fever, which usually resolve in approximately 7–10 days in immunocompetent hosts (Santos et al., 2009). Exposure dosage and host age and immune status are likely contributing factors to variability in the colonization level of the bacteria, incubation period, and severity of the symptoms between individuals.

15.3.1.3 Approaches using genome-wide association studies (GWAS)

Genetic approaches provide a promising way to enhance host resistance to SE infection and subsequently reduce food contamination. Indeed, many researchers have investigated candidate genes that may play a role in host resistance or susceptibility to *Salmonella* in chickens through GWAS using inbred chicken genetic lines (Calenge et al., 2009; Fife et al., 2011; Tilquin et al., 2005). A study by Fife et al. (2011) utilized genetic selection of several inbred chicken lines in order to map quantitative trait loci (QTLs) associated with lower caecum and gut colonization with *Salmonella* spp. The researchers were able to identify a single highly significant QTL on chromosome 2 in the 20 Mb region using a high-density SNP chicken panel. Additional research building on previously known QTLs associated with SE colonization have narrowed the focus to chromosomes 1, 2, 4, 6, and 12, creating a general consensus as to the candidate regions for follow up functional analysis (Calenge et al., 2009). Marker-assisted association studies have substantially improved our ability to understand the functional role specific genes may play in SE colonization. Furthermore, genetic selection will inform breeders as to the most effective breeding schemes to control these pathogens on commercial poultry farms.

15.3.1.4 Understanding host–pathogen interactions by analyzing host gut microbiota

Natural development of gut microbiota composition in young chicks occurs immediately following hatch. Hence, many factors could have an influential effect on the final composition of the microbiota profile. To understand the impact of early pathogen exposure and genetic background on the development of the gut microbiota in young chicks, Mon et al. (2015) conducted an experiment where two chicken genetic lines differing in MHC B-complex haplotypes were infected at 1 day old with SE. At 2- and 7-day postinfection, chicks were sacrificed and organs were harvested for both bacteriology and microbiota profile. In addition to the effects of host genotype and pathogen exposure, age of the chicks and postinfection time points were also considered for their respective impacts on the development of cecum microbiota using 16S rRNA gene sequencing. Results from the study indicated that there were significant differences in the composition of gut microbiota between 3- and 8-day-old infected chicks. The microbial diversity of the younger chicks was significantly lower, with a higher relative abundance of *Enterobacteriaceae* family microbes predominantly occupying the gastrointestinal niche, suggesting early colonization by this specific bacteria group. Host genotype, on the other hand, was found to have little effect on either susceptibilities to SE or establishment of the gut microbiota profile. Early introduction of SE pathogen inoculum to 1-day-old chicks was found to have the most profound effect on shaping the overall gut microbiota population by significantly reducing the microbiota diversity. The influence of infection with the SE pathogen on microbial population was also found to be more substantial at 8 days of age as compared to noninfected chicks. Overall, the study suggested that pathogen exposure in young chicks during the early posthatch period has a detrimental impact on the natural establishment of gut microbiota.

15.4 Abiotic stress—Heat stress

15.4.1 Background

Many abiotic stress factors have a significant negative impact on organisms, with heat stress being one of the most significant stressors in the poultry industry. Body temperature plays a huge role in core homeostatic functions, such as metabolism and heart rate (Roelofs et al., 2008). When these processes are perturbed or dysregulated, animals can suffer. There may be several physiological impacts associated with heat stress, including reductions in egg production, body weight, and nutrient utilization, resulting in substantial losses to both small and commercial farmers (Lamon, 2014). The economic losses associated with heat stress have been estimated to be between $125 and $165 million for the U.S. broiler poultry industry (St-Pierre et al., 2003). During a severe heat wave in North Carolina in 2011, over 50,000 chickens and 5000 turkeys died in 1 hour. As the threat of global climate change intensifies, an increasing effort has been made to understand the genetic control of resistance to heat stress as an approach to alleviating some of the environmentally induced pressures of climate change. Previous research has identified many potentially interesting candidate genes associated with heat stress resistance in both poultry and other livestock species, to further improve production animal welfare during heat stress (Lu et al., 2007; Turnpenny et al., 2001; Yahav, 1999).

15.4.2 Genomic methods to profile the heat stress response

Whole-genome transcriptome profiling has allowed researchers to understand the genetic effect that heat stress has on specific genetic pathways involved in modulating heat stress. A study by Lei et al. (2013) found that genes affecting hormones involved with appetite-regulating peptides were significantly altered during acute heat exposure. This discovery highlighted the significant genetic response involved in initiating heat stress-induced anorexia, which is a critical factor in reducing the nutrient intake of heat stressed birds (Yalçm et al., 2005). Further studies have also

Figure 15.2 Naked neck chicken from Morogoro, Tanzania.

found that heat shock proteins play a major role in maintaining protein stability within the host during prolonged periods of heat exposure. Mutations in heat shock protein related processes are associated with adverse reactions to heat stress, with many physiological processes failing to maintain proper function (Rimoldi et al., 2015). One of the most significant genetic findings related to heat stress is in the naked neck phenotype chicken (Fig. 15.2). The naked neck allele is in the middle of chromosome 3 and is a dominant allele (Lei et al., 2013). Individuals with the naked neck trait have better feed efficiency and feed conversion, as well as higher body weights, during heat stress than individuals lacking this allele (Eberhart and Washburn, 1993). This finding has the potential to aid researchers in understanding how specific variants can be utilized to alleviate the negative impact of stress factors on weight gain and production efficiency. Further investigation is needed to improve our understanding of the impact and contribution that genetic factors can make toward improving food animal production in hot and dry regions.

15.4.3 Genome-wide association studies

To date, very few studies have been undertaken to identify genomic regions conferring heat tolerance in poultry. Van Goor et al. (2015) used whole-genome genotyping technology to identify several genomic regions associated with heat stress resistance in an advanced population by intercrossing Fayoumi and broiler lines for many generations. The Fayoumi line is more resistant to heat stress than the broiler line. These intercrosses enabled the researchers to discover potential causative associations between genetic markers and heat tolerance. This study has identified several genomic regions associated with heat stress in a narrow interval of 1-Mb on chromosomes 1, 15, and 22. Several other studies have also implicated chromosome 1 as a major locus involved in regulating host response to heat stress in red jungle fowl, Leghorns, and quail (Eberhart and Washburn, 1993; Bjorkquist et al., 2015; Sahin et al., 2003).

15.5 Conclusions and implications

Poultry welfare problems arising due to environmental stressors are caused by genetic factors, environmental factors, and the interactions between them. Genetic improvement of resistance to these environmental stressors faces great challenges as these phenotypes are complex traits. However, the continued development of new technologies has shown major advantages of using genomic approaches over classical genetic approaches, particularly by increasing efficiency and accuracy. Elucidation of molecular and cellular mechanisms of genetic control of traits conferring resistance to stressors will provide a platform from which to identify associated causative mutations. High-throughput genotyping technology allows us to simultaneously analyze genetic information at the genome level in thousands of animals. It is generally accepted that there are many genes with small genetic effects controlling these traits, which means that it requires studying large populations of animals (at least thousands, depending on the heritability and distribution of phenotypes for each trait) with diverse phenotypes in order to have sufficient statistical power for identifying these small effects. The cost to conduct such large whole-genome association analyses is still a major limiting factor in food animal research. Recent studies only provide the “tips of the icebergs” in terms of identifying causative mutations affecting resistance to environmental stressors in poultry. However, the results generated so far have resulted in great insights and reconfirmed the promise of this advanced genomic approach for addressing poultry welfare.

There are a number of ongoing studies aiming to improve our understanding of the effects of either abiotic or biotic factors on poultry performance and welfare. However, very little research has been conducted to understand the molecular basis of how the co-occurrence of both of these factors, especially in hot climates, is mediated by the host (poultry). Future studies on the elucidation of genetic resistance to the combination of both types of stressors is warranted.

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Backyard flock production

16

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16.1 Introduction

The raising of backyard poultry in developed countries such as the United States and the United Kingdom has become a growing trend in recent years. The increase in the number of birds being sold to nonpoultry industry consumers, a large web presence for owners of backyard poultry, and a rise in the availability of premade coops (Erchull, 2014) all suggest that the trend is only increasing. Despite this growing interest, very little is known about this population of poultry, especially what welfare challenges they face. This chapter will primarily focus on what is known about backyard poultry keeping in the United States.

In the United States, the National Animal Health Monitoring System (NAHMS) has conducted two cross-sectional studies of backyard flocks in 2004 and 2010. The first was in response to a 2000 outbreak of Exotic Newcastle Disease in Southern California, which involved many urban backyard flocks. While this study took place across 18 major poultry producing states, it only identified backyard flocks within 1 mile of commercial operations within these states and the information obtained from owners was only focused on the health, biosecurity, and movement of birds in rural environments (USDA, 2005). The second study investigated urban backyard flocks in four metropolitan areas: Denver, Los Angeles, Miami, and New York City. Again, this study focused on health and biosecurity (USDA, 2011, 2013). Canada, New Zealand, and the United Kingdom have also recently attempted small-scale assessments of backyard flocks (Burns et al., 2011; Karabozhilova et al., 2012; Lockhart et al., 2010), suggestive of a world-wide trend in backyard flock popularity.

The question that these surveys have not answered fully is who the people are who are getting backyard poultry, and why? Elkhoraibi et al. (2014) performed a survey of backyard flocks with the intention of understanding the demographics of flock owners, their reasons for keeping poultry, and health and welfare challenges faced by their flocks. Their survey had just under 1500 respondents, representing 47 states. While not as large in scope, Madsen et al. (2013) also performed a survey in the State of Maryland with the goal of understanding owner and flock demographics as well as management practices that may contribute to disease risk. The survey had 41 respondents located throughout Maryland.

Elkhoraibi et al. (2014) found that most flock owners were highly educated women with household incomes over $100,000. The majority of respondents had kept chickens for 2−5 years, and most had 1−5 birds and a self-professed "fair knowledge" of raising chickens. While Madsen et al. (2013) did not include as

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many detailed questions about demographics, they did find that the majority of respondents had kept chickens for 5 years or less, but had a median flock size of 38 birds. It is important to note here that the definition of a backyard flock is somewhat ambiguous. Elkhoraibi et al. (2014) define a backyard flock as having 50 or fewer birds, whereas Madsen et al. (2013) define a backyard flock as 1000 or fewer birds (a common definition). It is highly likely that these two surveys are sampling both small, nonindustry flocks, and small flocks involved in the egg industry which likely have some similar challenges, but also very different challenges when it comes to welfare issues. Madsen et al. (2013) do not separate their results by this distinction, and this likely explains the discrepancies between the two surveys.

When asked why they kept chickens, 95% of respondents answered as "food for home use," 63% as "gardening partners," and 57% as "pets" (owners could select more than one answer; Elkhoraibi et al., 2014). Most of the food for home use was in the form of eggs (Elkhoraibi et al., 2014). These results support the widespread attribution, especially in urban centers of the United States, of backyard poultry keeping to the local food movement (Erchull, 2014). People who support the local food movement believe that eating locally sourced food helps achieve environmental sustainability, provides for healthier and safer food, and improves animal welfare (McClintock et al., 2014). The local food movement has become popular, especially among millennials. Many people have adapted their yard to use as a source of local food. While many urban environments do not provide the space and resources needed for most animal-based food products, poultry require relatively small amounts of space and resources to provide a food product, namely eggs (Erchull, 2014).

Most backyard owners feel they receive many benefits from their flocks. Owners typically report satisfaction that they are providing better care for their chickens (especially in urban areas) than on commercial farms (Elkhoraibi et al., 2014; McClintock et al., 2014). While many flock owners first obtain chickens as a source of food, they often come to regard their birds as pets over time. Backyard chickens also allow owners to feel connected to their food supply, an important driver for keeping backyard chickens as mentioned earlier.

16.2 Welfare concerns

16.2.1 Housing and management

Proper housing of flocks is important to assure they are in good health and have their behavioral requirements met, and varies widely among backyard flocks. Housing begins with a shelter for the birds (Fig. 16.1). Elkhoraibi et al. (2014) found that 93% of respondents provided their flocks with an enclosed shelter. These shelters provide protection from the weather as well as predation. Birds that cannot escape adverse weather conditions such as rain, wind, and extreme temperatures are at higher risk for contracting disease.

Predation is often cited as one of the greatest causes of mortality for poultry that have access to the outside (Madsen et al., 2013). Avian predators (hawks, owls,

Figure 16.1 Two examples of backyard flock housing. The coop on the right is in a climate that permits an open area with nest boxes and a roosting area that can be closed at night. The one on the left is a more traditional coop with roosting and nest boxes inside a closable shelter, with an outdoor run for birds to exercise.

eagles, and sometimes crows/ravens, etc.) have been found to be the cause of most predation events, while carnivores (dogs, foxes, coyotes, cats, raccoons, etc.) have the highest success in wounding and killing chickens (Stahl et al., 2002). All of these predators occur in both rural and urban environments, showing the need for proper housing. Due to this risk of predation, some flock owners opt to keep their chickens confined in a run, or only let their chickens range freely when they are home (Elkhoraibi et al., 2014).

Poultry have particular requirements when it comes to housing in order to carry out their highly motivated behaviors (Appleby et al., 2004). The vast majority of flock owners appear to have an understanding of this, and most provide perching and a nesting area for their birds (Elkhoraibi et al., 2014). Chickens prefer elevated perches when they roost at night, and most coops provide perches at varying levels. Hens also seek secluded areas to lay eggs, and will readily find an area that is acceptable if one is not provided. As most owners prefer not to hunt for eggs, nesting areas are typically provided for the hens.

The amount of space per hen provided to flocks varies widely. Very little research has been performed to address the question of space needs in noncommercial and free range flocks. Mench and Blatchford (2014) used kinematic analysis to determine the amount of space needed for hens of a commercial strain of White Leghorn to stand, lie down, turn 180 degrees, and flap their wings. They found that the behavior that required the most floor space was wing flapping, ranging from 1085.6 to 2446.6 cm^2. However, this study did not take into account social spacing (how close the birds prefer to be to each other), and it used a strain of hen that is much smaller than most backyard breeds. Therefore it is difficult to generalize the results to backyard flocks. Until more research is available in this area, owners are forced to experiment with spacing and refine as necessary.

Another area of management that has a potential effect on welfare is the diet offered to the birds. Elkhoraibi et al. (2014) found that most flock owners (75%) feed a mix of commercially available feed and kitchen scraps. Only 21% of owners fed a commercial diet alone, and a small percentage (1%) fed only kitchen scraps or did not provide any feed for the birds. The vast majority of flock owners provided water at all times. Mete et al. (2013) found that 11% of backyard birds necropsied over a 5-year period ($N = 1301$ birds, primarily from Northern California) died of metabolic disease and toxicoses. Of these birds, 54% died of fatty liver hemorrhagic syndrome, which was strongly associated with obesity. Other nutrition-related causes of death included vitamin E and riboflavin deficiencies as well as calcium, phosphorous, and vitamin D imbalances, and zinc toxicosis. Access to clean, fresh feed and water are integral for optimal health and production. Commercially available feeds should be feed to backyard flocks, as they are formulated to provide an optimal diet.

16.2.2 Health and biosecurity

Disease is a major welfare concern for backyard flocks, yet owner awareness of disease appears to be highly variable. While Elkhoraibi et al. (2014) found that 59% of respondents reported their flocks experienced no health-related conditions in the past year, Madsen et al. (2013) found that 56% of flock owners had observed signs of disease in the past 6 months. When causes of mortality were examined for 1300 backyard chickens over a 5-year period, 60% of deaths were found to have been caused by infectious agents (Mete et al., 2013). Though disease is occurring in this population of chickens, owners may have difficulty in recognizing symptoms of disease. The discrepancy between the two surveys may also be due to the difference in sampling methods. As Madsen et al. (2013) sampled commercial small flocks as well as backyard flocks, it may be that small flock producers are better at detecting disease among their birds.

Mete et al. (2013) found that Marek's disease was the leading viral infectious agent, and *Escherichia coli* the leading bacterium. This is surprising, as both of these can be prevented or their risk reduced substantially through proper management and biosecurity. Marek's disease is a ubiquitous organism worldwide, but vaccines are available for backyard chickens, with most hatcheries providing this service. *E. coli* is best addressed through sanitation and reducing the transmission of bacteria between flocks.

Biosecurity, or the protection of agricultural animals from infectious agents (Stinson and Mete, 2013), is achieved through a program of actions used to reduce the transmission of disease agents between flocks. Madsen et al. (2013) found that the majority of flock owners washed their hands, and had visitors wash their hands before and after handling birds. However, the majority of owners never wore designated clothing or footwear in bird areas, or used footbaths. Elkhoraibi et al. (2014) found that most flock owners isolated new or sick birds from the rest of the flock. They also wore designated clothing and footwear when cleaning bird areas, but not when they were not cleaning. In both studies, approximately 50% of respondents said their chickens were exposed to wild birds. These studies, taken with the

Figure 16.2 An infestation of chicken body lice (*Menacanthus stramineus* (Nitzsch)). Note the large egg clumps at the base of the feathers. These lice are most commonly found on the vent feathers of chickens.

prevalence of disease, show that although people are generally aware of practices involved in biosecurity, they do not have a full understanding of reducing the risk of transmitting diseases.

Along with the risk of disease, backyard flocks are also at high risk of external parasites due to poor biosecurity, or a lack of knowledge about how to detect or treat parasite infestations (Fig. 16.2). A recent survey of backyard flocks by Murillo and Mullens (2016) found a high diversity of parasite species that exceeds what is routinely observed in commercial flocks. Parasites observed included chicken lice, mites, and fleas. They did not observe soft ticks or bed begs, though these have anecdotally been reported in backyard flocks. Eighty percent of the flocks surveyed had external parasites, including the chicken red mite (*Dermanyssus gallinae* (De Geer)) which is blood-feeding and can cause anemia and death in heavily infested birds (Murillo and Mullens, 2016). Most of the parasite species that were found on the backyard chickens have not been observed in conventional commercial egg production systems. The observation of chicken red mites is troubling as infestations have direct welfare consequences, especially for commercial flocks as production moves toward cage-free production and systems housing birds outdoors.

16.2.3 Behavioral problems

Aggression and injurious pecking between birds are the most common behavioral issues reported by flock owners (Elkhoraibi et al., 2014). Although there are no studies that have looked specifically at the prevalence of these problems in backyard flocks, Mete et al. (2013) found vent picking to be one of the most common causes of death due to trauma, along with predation (2.6% combined). Aggression is a topic frequently found in online discussion forums and magazines specifically

Figure 16.3 Signs of aggression commonly seen in backyard flocks include feather loss on the head and pecking wounds on the comb. On the left is a hen with severe feather loss on the head, and several dark pecking wound scabs on the comb. On the right is a hen with moderate feather loss and two tears on the comb.

about backyard poultry. There are several types of pecking behavior in poultry, and the consequences of these behaviors can range from mild feather damage (Fig. 16.3) to more severe injury, even to the extreme of cannibalism (though this is likely rare in backyard flocks). Poor housing design and housing different age groups together are likely contributors to this behavioral problem. More work should be done to identify the actual rates and causes of aggression and injurious pecking and their impact on the welfare of backyard chickens.

Another common behavioral problem is that of egg eating. While this is less of a welfare concern for the birds, and more an annoyance for flock owners, in rare cases, it has the potential to contribute to cannibalism. Vent pecking is a common form of cannibalism, and can begin after a hen has laid an egg and her cloaca is still partially everted. If other hens peck at this soft, red area, the skin can be broken, and the resultant bleeding can attract other birds to peck at the area as well (Appleby et al., 2004). Hens that eat eggs can learn when eggs are being laid, and begin pecking the egg as it is being laid, increasing the risk of pecking the cloaca and breaking the skin. Egg eating is a very difficult behavior to change once it is established, and the best prevention is to maintain good hygiene in the coop by removing any broken eggs immediately and cleaning all traces of any spills. Collecting eggs several times a day reduces the likelihood of egg breakage.

16.3 Challenges for backyard flock owners

16.3.1 Food safety and public health risks

The propensity of backyard flock owners to have poorly developed biosecurity programs has implications for public health as well as food safety risks. Since the

1990s, zoonotic diseases such as *Mycoplasma* species, *Salmonella* species, and *Campylobacter* species have shown up in backyard flocks (McBride et al., 1991; Mete et al., 2013; Stinson and Mete, 2013). While the incidence of these zoonotic organisms is relatively small (only 3.5% of birds tested positive for zoonotic disease in Mete et al., 2013), the lack of precautions taken to prevent the spread is alarming for both chickens and their owners.

Of the zoonotic organisms found, *Salmonella* species are generally the most prevalent. *Salmonella* has garnered much attention by the Centers for Disease Control (CDC). From January to September of 2016, the CDC reported outbreaks of eight *Salmonella* species. A total of 895 people were infected from 48 states. Of those, 209 people were hospitalized with 28% of hospitalizations occurring in children 5 years or younger. There were three deaths associated with these outbreaks but only one was directly caused by bacterial infection, from *Salmonella infantis*. Although *Salmonella enteritidis* (SE) is a species that frequently causes disease in humans and was involved in one of the outbreaks, there were no deaths attributed to this outbreak (CDC, 2016).

SE has been tracked in laying hen flocks. Its prevalence in backyard flocks appears to be less than that in commercial laying hen flocks. An epidemiological study of California commercial layer flocks found SE on 10.5% of the premises tested, whereas 92% of premises tested positive for other *Salmonella* species (Kinde et al., 2004). In comparison, routine fecal samples showed only a 2.4% (27 out 1095 birds) prevalence of *Salmonella* species in backyard flocks, with only one bird having SE (Mete et al., 2013). From 1990 to 2014, only five deaths have been attributed to *Salmonella* infections traced back to contact with backyard chickens (Basler et al., 2016). While the rate of *Salmonella* infections in humans is low, it represents a considerable health risk due to the possible severity of the disease. SE is generally not a welfare concern for the birds, as it does not typically cause illness in chickens. However, other *Salmonella* species, such as *Salmonella pullorum* (SP), do infect and cause illness in chickens. Dailey et al. (2016) sampled 11 free-range and pasture-based systems (number of birds per flock ranged from 12 to 3666) for SP antibodies and found all but one flock had been exposed to this organism, with 100% of birds testing positive in three of the flocks. Although they had a small sample size, this study shows that SP may be a risk for birds that have access to the outdoors.

Transmission of *Salmonella* has been linked to risky behavior by flock owners. A study in the Seattle area of Washington asked owners from 50 households about bird health, *Salmonella* knowledge and risks, and biosecurity (Kauber et al., 2016). The caretaking practices of the households were also videotaped. They found that although participants were aware of the risks of *Salmonella* in regard to live poultry, they did not perform risk-reducing behavior. In fact, 25% of households reported they kiss and/or snuggle the birds, touch their mouth before washing their hands, and eat or drink near the chickens. This high risk behavior, coupled with poor biosecurity programs, suggests a high risk of *Salmonella* spreading between flocks, causing illness for both chickens and humans.

Another burgeoning area of health concern for both chickens and humans is lead poisoning. Backyard chickens, especially in urban and suburban areas, have increased exposure to lead-based paints in housing and bedding, or from contaminated soils (Scelfo, 2012). Hens showing signs of acute lead toxicity can suffer from muscle weakness, reduced intake of feed, weight loss, anemia, and a drop in egg production (Salisbury et al., 1958). Even low levels of exposure have been shown to slow the growth of broiler chickens (Bakalli et al., 1995).

In examining case studies, Roegner et al. (2013) found that often hens did not display clinical signs of lead toxicity, but rather appeared healthy and well producing until an unexpected death. As poultry can deposit lead into the eggs (Jelinek, 1982; Trampel et al., 2003), this poses a real threat to public health, especially to children who may be consuming those eggs. Most flock owners are unaware of the potential threat of lead in the environment, and Roegner et al. (2013) strongly advise having eggs and blood samples tested for lead. Sources of lead should also be identified in the environment and removed. Owners should also educate themselves about the signs of lead toxicity in chickens, as the birds may be suffering from exposure but not showing acute symptoms.

16.3.2 Municipal regulations

Many urban areas, and even county municipalities to some extent have laws and ordinances that prohibit the raising of poultry. However, the rise in the popularity of backyard chickens has brought about citizen engagement in trying to change these laws and ordinances. Community members have been quite successful at this, with many large urban areas such as New York City, San Francisco, and Los Angeles all changing city ordinances to allow keeping poultry. While most of the ordinances address noise, aesthetics, and potential nuisance issues like odor, they do little to educate owners about health and welfare problems (Erchull, 2014).

Most regulations are concerned with structural requirements and setbacks for coops, as well as the number and sex of birds to allow. These provisions vary widely by community, and are based less on the behavior and health of the flocks than on what is acceptable to the community. Barriers to local food production are often created by these provisions, such as by prohibiting breeding poultry for replacement stock, or using males for meat.

While Elkhoraibi et al. (2014) found that few owners wanted to produce chicken meat, lower income families may have a stronger desire to do this. Most urban centers prohibit the slaughtering of chickens, but those that do allow the practice certainly do not provide instruction on humane slaughter (Erchull, 2014). Enforcing these ordinances is also problematic, with Animal Control agencies often given enforcement power but no funding to perform this task. When complaints are made, enforcement agents often do not have the knowledge base required to appropriately assess backyard flocks.

An unintended effect of these ordinances that allow poultry has been the issue of how to dispose of unwanted poultry. These birds cannot be slaughtered, and euthanasia is often not an option as owners do not know how to perform this action and have difficulty finding a veterinarian to assist them. City animal shelters have seen an increase in relinquished poultry, but typically have neither the resources nor staff knowledge to properly care for the birds. Chickens being released into rural and urban areas are becoming quite a common problem as well (Serverson, 2009). Providing for the proper care of these unwanted animals is of utmost importance for improving their welfare.

16.3.3 Access to information and veterinary resources

While information on backyard poultry can readily be found on websites, blogs, and in magazines, the quality of that information is often questionable. Elkhoraibi et al. (2014) found that the majority of flock owners wanted more information on topics related to health, biosecurity, and euthanasia. Despite this, only 19% of flock owners responded that they view general/avian veterinarians as a source of information. This is perhaps not surprising, given that veterinary services are difficult to obtain for backyard chickens as most companion animal veterinarians are not trained in poultry medicine. There are veterinarians who focus on poultry medicine, but they typically work for the commercial sector and do not provide service for noncommercial clients due to the biosecurity risks.

Most states in the United States have diagnostic laboratories that provide necropsy services for the commercial poultry industry. Their services are also available to backyard flock owners for free or low cost, however, they are typically underutilized. Elkhoraibi et al. (2014) found that only 2% of flock owners used diagnostic laboratories, whereas Madsen et al. (2013) found 14% used these services. However, a review of the use of diagnostic services in the State of California shows promise for an increase in this rate. A Backyard Flock program was instituted by the California Animal Health and Food Safety laboratory system in 1998 as a surveillance program to monitor highly pathogenic avian influenza and exotic Newcastle disease. This program was designed to provide diagnoses and disease information to improve flock management and biosecurity while tracking disease in a population of birds from which it is difficult to collect information (Stinson and Mete, 2013). This program saw a 383% increase in submissions from 2007 to 2012.

While there appears to be an increase in the use of services to determine the causes of death in backyard flocks, it is puzzling that few flock owners report having biosecurity programs and a general lack of awareness of diagnostic services is high (Elkhoraibi et al., 2014; Kauber et al., 2016; Madsen et al., 2013). It could be that flock owner awareness of diagnostic services is rising, and that they are beginning to use these services with an intent of bettering the health and biosecurity of their flocks. However, because little advice is often given after the diagnosis, they do not know how to proceed. Further efforts to understand why there appears to be little follow-up after the diagnostic lab results are needed, with greater education about what to do with that information to improve flock care.

Humane euthanasia and carcass disposal are also areas where flock owners have expressed a need for more information and training. As veterinary services are difficult to obtain, and often underutilized, this represents a major welfare concern. The only study that investigated why and how chickens are killed to date has been Elkhoraibi et al. (2014). They found only 25% of respondents reported killing a chicken in the previous 12 months. The reasons provided for killing chickens were for meat, illness or injury, to get rid of males, cull nonproducing hens, and because birds were overly aggressive. Urban owners were less likely to kill chickens than those in rural areas.

While birds that are killed for meat commercially are regulated for slaughter methods, backyard flocks are not. Although Elkhoraibi et al. (2014) did not ask about methods specifically for slaughter versus euthanasia, they did find the most common method for killing reported was a killing cone, or some other related method involving severing the neck with a knife. Other methods reported for killing birds included decapitation, cervical dislocation, gunshot, and gas (generally using dry ice purchased from a grocery store). Most of these methods are approved by the American Veterinary Medical Association (AVMA, 2013), but many require appropriate training, which backyard flock owners do not receive. Regardless of the method, this is an area of critical welfare concern that needs to be addressed.

Once a bird has been euthanized or has died, many flock owners are unsure of how to properly dispose of the carcass. The most common methods of disposal seem to be burial on premises/composting and placing in the trash (Elkhoraibi et al., 2014; Madsen et al., 2013). Other reported methods include using diagnostic laboratories, feeding to wildlife/other animals, or incineration. With the prevalence of disease risks discussed earlier, these methods have potential to be problematic in terms of disease transmission between flocks and a concern for public health.

16.4 Conclusion

Backyard flocks of chickens are increasing in the United States as part of a global trend. The main force driving this increase seems to be the local food movement, and the desire of consumers to reduce environmental impacts of food production and concerns about animal welfare. However, there are still welfare concerns for backyard chickens that need to be addressed. Although this population of chickens is difficult to study, researchers are beginning to gain some understanding of the challenges facing backyard flocks. Education and access to quality information appear to be key challenges for backyard flock owners. While limited information on health and biosecurity is available, it appears owners are unsure of how to implement that information. The improvement of welfare for backyard flocks will involve both a better understanding of housing, behavior, and disease risks as well as better communication and outreach to owners.

Future research dealing with this population should focus on better understanding the variation in housing and husbandry, and how that variation affects the welfare of the birds, both physiologically and behaviorally. Potential solutions for many challenges, such as reducing predation, should also be investigated. A greater understanding of the potential human health risks of backyard flocks, combined with information on management practices that optimize welfare are greatly needed to inform policymakers struggling with creating ordinances and legalizing backyard poultry.

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Mass depopulation

17

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17.1 Introduction

17.1.1 The need for mass depopulation strategies

In the poultry industry, mass depopulation (also known as mass culling or emergency killing) refers to the killing of large numbers of birds at their production site. Historically, the most common reason for doing this has been to control disease, where killing of poultry on farm is necessary to minimize the risk of disease being transmitted to other poultry, and, in the case of highly virulent potential zoonoses, to protect public health. This "stamping out" of infected flocks can involve the killing of very large numbers of birds, and includes not only birds infected with the disease, but also healthy poultry in the surrounding area (Galvin et al., 2005). Increasingly however, mass depopulation is also being considered for the routine killing of low value poultry at the end of their productive life (e.g., laying hens), to reduce economic and welfare costs associated with catching, transport, and traditional slaughter (Turner et al., 2012; Webster et al., 1996). A further application of mass depopulation is to rapidly kill poultry in response to natural disasters, building collapses, and other unpredictable events.

The most important poultry disease necessitating mass depopulation is Avian influenza (AI), although other diseases such as Newcastle and Marek's disease are also associated with on-farm culling (Benson et al., 2012; Sparks et al., 2010). AI is caused by the influenza virus type "A" and can affect several species of wild birds, pet birds, and farmed poultry. There are many strains of AI viruses which generally fall into two categories: low pathogenic (LPAI) strains that typically cause few clinical signs in birds and highly pathogenic (HPAI) strains that cause severe clinical signs and high mortality. A highly pathogenic strain of AI (H5N1) emerged in Southeast Asia in 1997 and has subsequently spread throughout Asia, the Middle East, Africa, Europe, and the Americas. HPAI strains are associated with illness and death in humans who have had close contact with infected birds. AI is a listed disease under the Terrestrial Animal Health Code of the World Organisation for Animal Health (OIE). Notifiable AI includes two subtypes, H5 and H7, both of which must be reported to the OIE. Their records reveal large numbers of outbreaks worldwide, highlighting the widespread extent of AI and the ongoing threat posed to the poultry industry. Between 2003 and 2016, the largest number of outbreaks by country was reported by Vietnam (2745), Thailand (1141), and Egypt (1084) (OIE, 2016).

Because mass culling has been the risk management strategy of choice to deal with notifiable disease outbreaks, the animal welfare, economic and societal

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impacts of mass depopulation are matters of global concern. The scale of the intervention required to deal with disease outbreaks is related to the increasing scale of production. For example, in the United States in 2015, a single AI outbreak led to the mass depopulation of 34 million birds on 77 Iowa farms (Johns, 2015). Clearly, the need to respond to highly infectious disease outbreaks necessitates the availability of effective and humane methods for mass depopulation, and these must be employed while taking into account other vital considerations, especially when highly virulent and potentially zoonotic pathogens are involved. In this chapter, the strengths and weaknesses of various methods of mass depopulation will be reviewed, with a focus on bird welfare in relation to emergency killing for disease control. Where appropriate, insights from previous experience of the provision of mass depopulation in response to large-scale disease outbreaks will be incorporated.

17.1.2 Important considerations for the use of mass depopulation for disease control

A number of techniques including mechanical, electrical, pharmacological and gaseous have been employed for mass depopulation in disease control situations for poultry (Raj, 2008). Some have been adapted from routine slaughter methodology, while others have been designed specifically for mass culling. Essentially, all of these killing methods act by three routes: direct or indirect hypoxia leading to complete loss of brain function; direct depression of neurones necessary for life functions (such as depression of the central nervous system respiratory center leading to cardiac arrest); and physical disruption of the brain (Galvin et al., 2005).

The decision to depopulate is often made at government level and the societal and ethical issues involved include concern for the welfare of the animals involved and aversion to the killing of healthy "at risk" animals (Hueston, 2007). Indeed, killing for disease control purposes has been described as an "emotional issue for everyone concerned" (Thornber et al., 2014) and the need to simultaneously protect animal health, animal welfare and human health is a significant challenge. For any method of mass depopulation to be suitable for disease control situations, there are arguably three aims: control the spread of disease, protect human health, and ensure humane treatment of the animals (Gerritzen and Raj, 2009). The prioritization of these goals will vary depending on context and is likely to depend on the disease involved (and consequent risk to public health), the availability of suitable culling methods and economic constraints. While different approaches have their own benefits and drawbacks which will be discussed later, a number of important considerations are relevant to all methods.

Bird welfare is a primary concern and it is reasonable to question whether the ethical standards required of emergency killing should be equivalent to routine slaughter. Even if this is presumed to be the case, it has been suggested that these standards may not be achievable since animal welfare may be compromised during mass depopulation due to inexperienced operators, time pressure, nonstandardized conditions on farm and the need to minimize risks to human health

(Gavinelli et al., 2014). These factors are likely to influence bird welfare via impacts on handling, killing method, and possibly efficacy.

While "euthanasia" is understood to describe killing that eliminates or minimizes suffering (usually involving smooth induction to loss of consciousness and rapid loss of brain function), depopulation has been described as "destroying animals as quickly and efficiently as possible, with as much consideration given to the welfare of the animals as practicable" (Thornber et al., 2014). The policy of the American Veterinary Medical Association states "Mass depopulation refers to methods by which large numbers of animals must be destroyed quickly and efficiently with as much consideration given to the welfare of the animals as practicable, but where the circumstances and tasks facing those doing the depopulation are understood to be extenuating" (AVMA, 2010). Nevertheless, in the EU there is an expectation that emergency plans will take into account "the need to achieve a humane death similar to slaughter," although authorities, in suitable circumstances, are allowed to apply exceptions that prioritize human or animal health concerns over animal welfare (Gavinelli et al., 2014). HPAI infections are associated with severe symptoms in the birds that can cause up to 100% mortality (Alexander, 1995), and thus mass culling of these flocks can be in the birds' own interests, although this will depend on whether the welfare impact of the killing method is less severe than the suffering caused by the disease. Even so, large numbers of healthy birds are killed in a demarcated buffer zone (protection zone) around the outbreak during epidemics, providing additional impetus to choose methods causing the least welfare harm (Gerritizen et al., 2006).

Methods for mass culling need to be practical, that is, able to be effectively deployed by available personnel. They must also have sufficient capacity and rate of throughput to deal with the required numbers of birds in a short time frame. The suitability of each method in a given outbreak will depend on factors such as the species and type of bird involved, as well as their husbandry and management. To achieve effective disease control, it is important that all the birds are killed in each culling event and to protect welfare, death must be confirmed before disposal (Thornber et al., 2014). The manpower, equipment, and raw materials needed (e.g., gas) will impact the cost of the cull per bird which must not be prohibitive, especially in relation to outbreaks where large-scale depopulation must take place. Depending on the method used, local environmental contamination may also be a consideration. Given the time critical nature of the response to a disease outbreak, suitable methods must be available for rapid deployment, and must not require long lead times for preparation or transportation to farm sites.

Finally, the method itself should minimize disease transmission risk, both to other poultry flocks and, in the case of potentially zoonotic pathogens, to human operators conducting the cull. Ideally, handling and transportation of living birds from infected flocks should be avoided to minimize risk of disease transmission, and this has led to the development of a number of "in situ" culling approaches. Killing whole flocks of birds in their production housing provides limited control of the killing process, while bringing birds to a killing device allows the process to be controlled for individuals but involves handling which may impact welfare and increase biosecurity risks. Several "whole flock," small group and individual bird approaches have been developed and these are reviewed below. Various methods reportedly used in disease outbreaks in the past are not recommended including asphyxiating birds in plastic bags, putting birds in plastic bags and burning them, gassing with hydrogen cyanide, gassing with impure carbon monoxide, and injection with any chemical except barbiturates (EFSA, 2005). These procedures can be considered to be completely unacceptable on welfare grounds and will not be discussed further.

17.2 Mass depopulation methods

17.2.1 Containerized gassing units/mobile gas systems

Use of lethal gases is the most common (and well-studied) approach to on-farm culling, and gases have been applied in containers, enclosures, whole houses, and foam. However administered, gas mixtures do not induce unconsciousness immediately, so relevant bird welfare considerations during killing are aversive reactions and respiratory effects in the conscious phase (McKeegan et al., 2011). The time taken to achieve the loss of consciousness and death is also important; ideally the induction of anesthesia should be smooth and rapid. Responses of poultry to various gas mixtures in the context of routine slaughter have been extensively researched (e.g., Gerritzen et al., 2000; Lambooij et al., 1999; McKeegan et al., 2007) and there has been debate around which are most humane (reviewed in Raj, 2006). There have been fewer welfare assessments of application of gases for on-farm killing than for routine slaughter, but in terms of physiological and behavioral responses, the same principles apply.

Inert gases that displace O_2 from air (such as argon or nitrogen) may be used to kill birds as well as CO_2 which induces rapid unconsciousness when inhaled at high concentrations (e.g., Forslid et al., 1986; McKeegan et al., 2007), and various stunning systems used for routine slaughter apply these gases alone or in combination. Several studies have demonstrated that exposure to CO_2 at high concentrations is aversive to birds (e.g., McKeegan et al., 2006; Sandilands et al., 2011) and inhalation of CO_2 is painful in humans at concentrations over 65% (Hari et al., 1997). In addition, gas mixtures containing CO_2 also induce signs of respiratory distress before loss of consciousness (McKeegan et al., 2007). Inert gases do not raise these welfare issues and have fewer health and safety implications for operators but are costly (in the case of argon at least) and are more difficult to apply since they are not heavier than air and extremely low oxygen concentrations ($<2\%$) must be achieved for them to be effective (Galvin, 2005). Carbon monoxide will kill poultry at concentrations of 4%–6% (Galvin, 2005), and was used during the epidemic of AI in the Netherlands in 2003 (Gerritzen et al., 2006) but its wider use has been limited due to significant issues related to the health and safety of human operators and the fact that it is explosive at concentrations above 10% (Raj et al., 2006).

The first on-farm gas killing systems to be developed were containerized. Raj and Gregory (1990) reported early research comparing immersion of broilers in containers of 45%−55% CO_2 (2% O_2) or Argon (5% O_2) and showed that Argon was not effective (the birds remained fully conscious) while CO_2 was successful. They noted the importance of eliminating air pockets trapped between the birds even when using gases heavier than air to ensure an effective cull (Raj and Gregory, 1990). In the United States, Webster et al. (1996) described a CO_2-based containerized method for humane on-farm killing of spent laying hens, and although this was not designed for disease control, they showed that a mobile modified atmosphere killing (MAK) unit could be effective. CO_2 has emerged as the primary gas used in on-farm culling due to its effectiveness, as well as being inexpensive and widely available (Van den berg and Houdard, 2008). While 40% CO_2 in air is sufficient to kill chickens (Gerritzen et al., 2004), death is more rapid on exposure to concentrations above 55% (Raj and Gregory, 1990). It has been suggested that ducks and geese require longer exposure times and concentrations above 70% (Van den berg and Houdard, 2008).

Early use of containerized gassing for emergency killing generally involved adding birds by hand to vessels full of CO_2 (including improvised containers such as skips (dumpsters) and waste bins; Galvin, 2005) but the methodology has continued to evolve. Gerritzen et al. (2006) reported on the use of several containerized or mobile types of gas killing devices during the AI epidemic in the Netherlands in 2003. Although varying in size (between 2 m^3 and 35 m^3) and efficiency, all used CO_2 and all were fully effective, with no survivors. Birds were either placed in the gas in crates or directly through a hatch in the top of the container. Wing flapping, jumping, and hyperventilation were observed in a high proportion of birds directly after placing them in the gas containers, and this lasted between 30 seconds and 2 minutes. Although the concentration of CO_2 at the bottom of containers is effectively 100%, Gerritzen et al. (2006) noted that the time to unconsciousness and death varied in relation to the number of birds that were introduced into the container in a short time, presumably related to the dilution of CO_2 with air carried in by birds in their feathers and respiratory systems.

Use of a "ground panel enclosure" for killing of turkeys with CO_2 was reported by Kingston et al. (2005). Turkeys (4200) were walked into a rectangular enclosure (56 × 24 × 4 feet) formed of plywood sheets and tarpaulins built inside the poultry house (a similar approach was also used in trials with broiler breeders). CO_2 was introduced, and was associated with wing flapping and increased vocalizations within approximately 1 minute of gas introduction. The enclosure successfully contained the gas, aided by lowering of the tarpaulin after the end of wing flapping at around 5 minutes after CO_2 was introduced with the aim of increasing CO_2 concentration. Mortality of 100% was achieved. This method helpfully avoided extensive bird handling, which is especially useful for large poultry species. Improvised enclosures consisting plastic wrapped around "flats" (transport modules holding 350−400 birds), used in Newcastle disease outbreaks, were also described by Kingston et al. (2005). They also described a "metal chamber enclosure" designed to be lowered over a transport module (using a forklift) before being filled with CO_2. The time required to reach the target concentration of 50% CO_2 was around 1 minute, and sound and movement from the birds ceased in less than 2 minutes. In all cases, the authors commented on the importance of limiting time in the enclosure prior to gas application, due to a very rapid increase in temperature and humidity caused by close confinement and lack of ventilation. This is also an issue in whole house gassing (WHG, see Section 17.2.2).

While containerized CO_2 euthanasia has been shown to be technically straightforward and highly effective, bird welfare concerns have been raised about this technique. Although the time to death is generally short, the fact that poultry find high concentrations of CO_2 extremely aversive and possibly painful (EFSA, 2004) is a significant concern. In addition, adding live birds to containers filled with a gas could cause injury because of rough handling and the small size of the hole through which they are dropped, and there is also the risk of compression or suffocation caused by more birds being dropped into the container before earlier batches have succumbed to the gas (Raj et al., 2008a).

While poor welfare caused by any culling method has to be balanced against the suffering caused by the disease itself or the possible use of more distressing methods of killing (Raj et al., 2006), Raj et al. (2008a) argued that bird welfare during culling could be improved by finding a way to apply a gas mixture that is shown to be less aversive to poultry than a high concentration of CO_2. A system was sought in which crated birds could be reliably exposed to a nonaversive but lethal gas mixture. This work resulted in the Containerized Gassing Unit (CGU) system, which is fully described by Raj et al. (2008a). The system is based on application of a 20% CO_2 in Argon gas mixture (which is affordable and widely available as a welding gas combination) in purpose built containers. Birds are caught and placed in standard transport modules (which hold approximately 300 chickens), then introduced to a gas tight steel container (6.75 m^3). The CGU is then gradually filled with gas until less than 5% by volume of residual oxygen is achieved at the top of the container (this takes between 50 and 180 seconds depending on the gas supply type and the volume of air to be displaced plus a minimum "dwell" time of 3 minutes to allow the birds to become unconscious and die; J. Sparrey, Personal Communication). Given that the gas mixture is denser than air, there is gradual filling of the container and birds in each layer of the module are exposed to rising gas mixtures, therefore time to death will vary slightly within the container (Raj et al., 2008a). The CGU system has also been shown to be effective in culling ducks and geese, provided that a residual oxygen concentration of 2% is achieved (Raj et al., 2008a) and longer dwell times are allowed (5 minutes, J. Sparrey, Personal Communication).

Webster and Collett (2012) reported on the development of a mobile MAK small-flock depopulation system, building on related earlier work (Webster et al., 1996). Their aim was to target the system to small and backyard flocks, and they evaluated the system with both CO_2 and N_2 to kill a range of species. The apparatus consists of a trailer mounted metal chamber with a gas delivery system allowing the injection of CO_2 or N_2 (monitored with sensors). The approach was effective with automated control of gas delivery maintaining the gases at a set level. While continuous loading of birds was possible when CO_2 was used, with N_2 the birds had to be killed in batches to maintain the low levels of residual O_2 essential for effectiveness. The chamber was able to hold more than 544 kg of carcasses (equivalent to 79 turkeys or 600 broilers) which the authors note is sufficient capacity to deal with the majority of small flocks.

Available research and practical experience highlight a number of strengths and weaknesses associated with the use of containerized systems for mass depopulation. The most important strength is the flexibility of these systems, allowing them to be used in a range of circumstances where other methods are not suitable (for example to depopulate open-sided houses where WHG cannot be used). The methodology can be adapted to take account of farm size, poultry species, and even unpredictable aspects such as adverse weather conditions (Raj et al., 2008a). Containerized killing systems are particularly useful for depopulation of small flocks, especially backyard or "hobby" flocks which are likely to be at greater risk of disease via increased exposure to various vectors, including wild birds (Webster and Collett, 2012). Containerized systems are easily made mobile and accessible, and it has been argued that they have an essential role in disease control (Raj et al., 2008a). Their modest cost and relatively simple operation is also beneficial, and the sealed nature of containers allows a wider range of gases (including inert and nonaversive gas mixtures) to be used compared to WHG. While generally considered to be humane, the welfare impact of containerized methods depends primarily on the gas mixture used along with application of good procedures such as well-controlled timing of addition of birds to containers and regular checking for survivors (Galvin, 2005).

The major weakness of containerized systems is that individual birds need to be handled to introduce them to the gas (either directly or after placing into crates) which is likely to compromise bird welfare via stress and injury. Crucially, handling also significantly increases the risk of exposure of operators to infectious agents and potentially distributes pathogens more widely on air currents (Gerritzen et al., 2004, 2006; Raj et al., 2006). Although protective clothing may be worn, this remains a significant concern when dealing with potentially zoonotic, highly virulent pathogens. As with all gas-based systems, safety considerations apply when using containers, particularly when there is a risk of CO_2 escape from them due to physical displacement by the birds. This could potentially compromise the health and safety of workers in the immediate surroundings, especially during prolonged use (Raj et al., 2008a). Low to moderate throughput is also a major drawback when dealing with large flocks, as containerized systems are labor intensive (Van den berg and Houdard, 2008). The capacity of mobile gas killing devices depends on the size and number of containers available at the site (Gerritzen et al., 2006); for example Raj et al. (2008a) estimated that operating with two CGUs would allow killing of up to 5000 birds per hour. While flexible and proven to be effective, the limited throughput of these systems represents the biggest barrier to their use when there is need for a rapid response to a large disease outbreak.

17.2.2 Whole house gassing

The method of applying large volumes of lethal gas directly to whole houses of birds (termed whole house gassing or WHG) to kill them in situ was developed because it eliminates the need for bird handling, reduces contact with infective materials, and increases capacity (Raj et al., 2006). WHG is performed by introducing the gas into a poultry house and this may be delivered directly from a liquid source, vaporized from a liquid source before delivery into the house, or introduced as a liquid via pipes drilled with small holes placed inside the house. In all cases, the aim is to release large volumes of gas evenly over the birds and the building should be sealed as effectively as possible to contain the gas (Galvin et al., 2005; Van den berg and Houdard, 2008). Gerritzen et al. (2004) examined the efficacy of a range of gas mixtures for WHG of broilers including 100% CO_2, 50% N_2/50% CO_2, and 30% O_2/40% CO_2/30% N_2 followed by 100% CO_2. In 2-week-old birds, 10% survived the three part mixture, so it was not tested further. At 6 weeks of age, 30% of birds survived the 50% CO_2/50% N_2 mix, and only the 100% CO_2 mix resulted in a bird level concentration of over 40% (considered sufficient to ensure death). Any gas used in depopulation must be capable of killing all birds, and the use of denser than air gases makes it possible to achieve lethal concentrations in poorly sealed poultry buildings. Therefore only 100% carbon dioxide has been widely used in WHG, though carbon monoxide has also been trialed (Gerritzen et al. 2006; Raj et al., 2006). The difficulty in maintaining low enough levels of residual O_2 prohibits the use of inert gases in WHG (Galvin et al., 2005).

Although CO_2 is effective, its use in WHG gives rise to a number of specific welfare concerns. As previously described, exposure to CO_2 is aversive and nociceptive, and it activates both central and peripheral chemoreceptors to evoke a potent respiratory response (McKeegan et al., 2007; Sandilands et al., 2011). Compared to container systems, the "gradual fill" nature of WHG with CO_2 makes it less likely that birds would come into contact with high concentrations of CO_2 while conscious, but this gives rise to concerns relating to extended times to achieve an effective kill because of the time taken to fill the whole building with a lethal concentration of gas (Raj et al., 2006). In addition, the delivery of large volumes of CO_2 from liquid sources is associated with extremely low temperatures (as low as $-78°C$) which gives rise to another welfare concern—the potential for severe cold stress and hypothermia. Such subzero temperatures also freeze any water vapor in the atmosphere resulting in an extremely dry atmosphere which could be painful to inhale (Raj et al., 2006). It is also possible that the force of the liquid plume entering the building could directly injure birds and there is a risk that the loud noise created by gas injection could cause the birds to panic and smother each other.

WHG was widely used for the first time in the Netherlands to control the AI outbreak in 2003, and Gerritzen et al. (2006) described its application. When carbon monoxide was used, the time taken to reach the required concentration of 1.5% was 15−45 minutes, and concentrations of up to 0.2% carbon monoxide were detected outside the houses. During CO application, vocalizations and wing flapping could be heard, and given that CO is lighter than air, it was sometimes challenging to achieve sufficient concentrations to ensure 100% mortality. Where used, liquid CO_2 was injected until a concentration of 40% was measured inside the house (as recommended, Galvin et al., 2005) taking up to 60 minutes, and this was maintained for a minimum of 30 minutes. No sounds of agitation or convulsions could be heard outside the buildings when CO_2 was applied in this way. Gerritzen et al. (2006) noted that application of CO_2 created a "fog" and reduced the air temperature in the building, but there were no obvious effects of this on bird behavior. It appeared that gas concentrations increased gradually, causing birds to lose consciousness before they inhaled high concentrations of CO_2 and there were few signs of severe convulsions. Gerrtizen et al. (2006) concluded that although WHG appeared to be effective, the procedure was difficult to control, and more information was needed about the rate of build-up of gas and temperature conditions experienced by the birds. Physiological and behavioral data from birds at critical locations in the house were needed to generate evidence-based procedures to protect welfare.

To learn more about the welfare implications of WHG, two commercially relevant studies were carried out in the United Kingdom. Sparks et al. (2010) evaluated the use of liquid CO_2 in a cull of 12,000 5-week-old pullets, delivered via a single entry point (a metal pipe, also called a lance). Temperature, gas concentration, and bird behavior were monitored throughout the WHG procedure, and as with improvised enclosures, it was noted that the temperature inside the building increased rapidly prior to gassing while the building was sealed. The target concentration of 45% CO_2 was reached just over 5 minutes after the commencement of gas injection (3.24 tonnes of gas was delivered), and the building remained sealed for 1 hour. Temperatures at bird level fell to −85°C within 6 minutes. Behavioral observations were unsuccessful because condensation inside the building caused a total loss of visibility. All of the birds were killed and the authors stated that "the appearance of the birds indicated that the onset of unconsciousness was rapid and not associated with a significant amount of uncontrolled activity." Combining previous work describing responses of chickens to CO_2 with their gas concentration measures, Sparks et al. (2010) estimated that the time to loss of posture in the pullets was approximately 38 seconds, at which time the temperature was not yet below 0°C. Based on an assumption that the birds ceased convulsing at 24% CO_2 (equating to 86 seconds after introduction to the gas), the temperature at bird level at that time would have ranged from −1°C to −5°C. They concluded that the birds had died (or were near death) before they were exposed to very low temperatures during WHG.

This work provided useful insights but did not provide detailed information about time to loss of consciousness in birds undergoing WHG or the temperatures they individually experience. This was addressed by McKeegan et al. (2011), who measured the physiological responses of 10 "sentinel" hens during the WHG of a 28,000 bird flock of spent hens with liquid CO_2. Using a novel telemetric device designed to operate in extreme conditions, they measured body temperature, respiration, cardiac (ECG) and brain activity (EEG) in the sentinel birds, as well as gas concentration and ambient temperature. The CO_2 injection time was 19 minutes, by which time the concentration in the house was 45% (14.5 tonnes of CO_2 were delivered). In response to CO_2 delivery, house temperatures fell rapidly and a minimum of −13.1°C was recorded in the immediate vicinity of one instrumented bird. Cloacal temperatures decreased gradually with the lowest temperature recorded being 37.6°C, but body temperature measurements confirmed that the birds did not die of hypothermia. Time to loss of consciousness (based on distinctive EEG characteristics) ranged from 6.0 to 10.5 (average 7.8) minutes after the onset of gas injection and time to death was between 13.7 and 22.1 minutes. These data confirmed that the gas acted gradually as an anesthetic before causing death, and that the birds were unconscious before subzero temperatures could be experienced. The birds responded to CO_2 delivery with distinctive cardiac and respiratory responses, in particular deep breathing, which was experienced by birds over a relatively prolonged period (4−8 minutes). However, the concentration of CO_2 achieved while the birds were conscious (approximately 20%) would not have stimulated nasal and oral nociceptors. McKeegan et al. (2011) concluded that fears about the use of liquid CO_2 causing cold-shock and pain were unfounded, and although WHG has welfare costs, these may be outweighed by the value of such a highly practical and reliable emergency killing method.

Further evaluation of the welfare impact of WHG with CO_2 was carried out by Turner et al. (2012), who measured EEG and ECG in 12 sentinel hens killed in a flock of 24,000. Their results indicated that instrumented birds lost consciousness within 2 minutes of CO_2 levels reaching 18%−20%. Behavioral monitoring revealed that the birds showed headshaking, gasping, and clonic convulsions and EEG data suggested that brain death was rapid (within 5 minutes of gas delivery onset). These shorter time-to-death durations than reported previously by McKeegan et al. (2011) are likely to relate to faster rates of gas delivery in the later study (reported to exceed 20% CO_2 at 14 seconds after injection commenced and exceeding 60% at maximum, Turner et al., 2012). This study further allayed fears of hypothermia since the body temperature of monitored birds remained at or near normal while birds were alive.

Increasingly, CO_2 WHG of spent hens is being used as a routine depopulation method, and Berg et al. (2014) reported on outcomes of 150 culls that took place in Sweden between 2008 and 2010. During WHG with CO_2, large and variable temperature decreases were recorded, and time to loss of posture (a proxy for loss of consciousness) was between 3 and 5 minutes after gas delivery. The average timing from gas introduction to the last sign of life was 11.2 minutes. Veterinary reports showed that six out of 150 killings were associated with significant welfare issues, including failure to achieve adequate gas concentration, extended time between building ventilation shutdown (VSD), sealing and gas delivery causing heat stress, and unintended killing of neighboring birds via gas leakage to nearby houses. This study of long-term use of the WHG technique provides evidence that it is generally humane and is being carried out in compliance with legislation; however, its routine application was associated with a number of welfare hazards which could be ameliorated through improved operator knowledge to limit errors.

Extremely large numbers of birds can be killed in a short time using WHG, and its impressive capacity is a major advantage. Administration of liquid CO_2 from a tanker is relatively simple and inexpensive to implement, and can be carried out with limited personnel (Sparks et al., 2010). With the use of a single externally applied lance, WHG can potentially be employed without personnel even having to enter the poultry house (as long as vent sealing from the outside is possible). Killing the birds inside their houses without any handling reduces the spread of infection, a vital consideration in disease control scenarios. However, some technical support is needed, and health and safety issues relating to very low temperature liquid and high volumes of gas must be dealt with. Significant gas leakage during WHG has been reported (Sparks et al., 2010) so the operation of an "exclusion zone" around the house is advisable. Such leakage makes the technique rather wasteful of gas, and large quantities are needed, which could become a limiting factor in a large-scale outbreak. After culling, the possibility of people entering the house before it has been fully ventilated is a risk, and strict standardized operating procedures must be implemented to protect worker safety (Raj et al., 2006). Although not suitable for all types of poultry housing, WHG has proven to be reliable in widespread use for both emergency and routine depopulation. It is also considered to be "relatively humane" (Sparks et al., 2010) and acceptable as a mass depopulation method (McKeegan et al., 2011). Concerns have been raised about whether it will be difficult to remove dead birds from cages if this cannot be accomplished before rigor mortis sets in, but this issue has not been studied.

17.2.3 Low−medium expansion water-based foam

The use of water-based low expansion foam was developed in the United States in 2006, and involves covering birds with a blanket of modified fire-fighting foam. Immersion in the foam blocks the airway of the birds causing mechanical hypoxia and ultimately death (Benson et al., 2007; Dawson et al., 2006). The foam is generated by specialized equipment with a mixture of water, commercial foam concentrate, and gas (usually atmospheric air) (Benson et al., 2012). Foam is described by its expansion ratio, which is the ratio of volume of foam formed to the volume of solution used to generate it. Low, medium, and high expansion foams have expansion ratios of 2−20:1, 20−200:1, and >200:1, respectively. Typically, foam is used to kill birds in situ in their production housing, advancing across the house until all the birds are covered; with low−medium expansion foam the aim is to achieve a depth of 15−30 cm above the birds' heads (Benson et al., 2012). Foam is applied against a side wall or ceiling and allowed to flow over the birds, to allow coverage without direct application (Benson et al., 2007). While air-filled foam represents a method that does not employ potentially aversive gas mixtures, welfare concerns have been raised since occlusion of the airway is equivalent to drowning or suffocation (technically defined as physical separation of the upper respiratory tract from atmospheric air), neither of which are recognized as humane under European legislation or the OIE guidelines on the killing of animals for disease control purposes (Raj et al., 2008b). A possible concern is eye and skin irritation from the foam since foam concentrates may contain hydrocarbon surfactants, solvents, stabilizers, alcohols, propylene glycol, and corrosion inhibitors (Benson et al., 2007), but this has been largely dismissed due to the short time birds spend in the foam.

Initial evaluation of low−medium expansion foam (air or CO_2 filled) showed that the approach was effective, and that broilers died faster on exposure to water-based foam compared to CO_2 application in a polyethylene tent (Benson et al., 2007). Immersion in foam caused cessation of ECG activity in individual birds in 73 seconds in CO_2-filled foam, and 64 seconds for air-filled foam. The authors concluded that adding CO_2 to the foam does not enhance its efficacy and this was confirmed in later work (Alphin et al., 2010). This is not surprising given the mode of action of the foam which is to physically block the airway and in any case, the gas is trapped in the very small bubbles which are characteristic of low expansion foam and thus not available to the birds. In groups of broilers on the floor, air-filled low expansion foam caused cessation of ECG activity in an average of 274 seconds (Benson et al., 2007). Postmortem examination of the birds showed that blood was present in the trachea, syrinx, and bronchial tree in broilers subjected to foam, but this was also present in birds undergoing gassing with CO_2, and Benson et al. (2007) concluded that these lesions were consistent with hypoxia, induced either physically (by foam) or chemically (by CO_2 gas). Plasma corticosterone concentrations suggested that death in the foam was no more stressful than exposure to CO_2; however, postmortem corticosterone levels are likely to be significantly affected by convulsive activity which occurred in both treatments. Based on accelerometer data, Dawson et al. (2006) reported that air-filled low expansion foam resulted in death of broilers in 2.54 minutes, compared to 2.08 minutes on exposure to CO_2.

These early trials also demonstrated that characteristics of the foam such as cohesion, flowability, and moisture content were determined by the type of foam concentrate, the proportion of foam concentrate used, and the generation method (Benson et al., 2007). It was noted that changes in the formulation of the foam mixture altered the characteristics of the foam and that for effective operation it was important to ensure that the foam did not become too dry, since drier foam does not "flow" consistently and is more easily broken down by bird movement, allowing air pockets to develop (increasing the risk of survivors). The USDA-APHIS guidelines (USDA-APHIS, undated) for water-based foam depopulation state that the bubble size from water-based foam used for poultry depopulation should not exceed 0.625 in. (1.58 cm) and preferably should be smaller, and this equates to a medium expansion ratio range of 25:1−140:1. Some experimental work on water-based foam, however, has been carried out with low expansion ratios (e.g., Benson et al., 2009; expansion ratio of 2.4:1).

Alphin et al. (2010) presented the results of EEG monitoring of individual broilers exposed to Ar/CO_2 gas, CO_2 gas, air-filled foam, and CO_2-filled foam. The primary outcome measure was "EEG silence" (isolelectric EEG) which occurred with CO_2 gas at 134 seconds compared to 195 seconds with Ar/CO_2. The foam treatments were similar with air-filled gas and CO_2-filled gas causing EEG silence at 134 and 120 seconds, respectively. However, time to isoelectric EEG does not equate to loss of consciousness (since loss of consciousness can occur before isoelectric EEG) and time to loss of posture was not recorded, making these results more difficult to interpret in welfare terms. Foam made with air produced slightly more consistent responses than foam containing CO_2, and both foam treatments produced less variable responses than the gas treatments (Alphin et al., 2010).

The action of low−medium expansion foam has been investigated in poultry species other than chickens. The responses of ducks, chuckar partridges, and quail were described by Benson et al. (2009), based on measurements of ECG and cessation of motion (with accelerometers). The foam effectively killed all species, despite fears that the method would not be effective for ducks because of their capacity to breath-hold as part of the diving reflex. In fact, ducks showed similar overall responses to other bird species, albeit with slower times to death. Caputo et al. (2012) compared water-based medium expansion foam and CO_2 gassing in White Pekin ducks using EEG, ECG, and accelerometer data. CO_2 acted faster than foam to cause unconsciousness, motion cessation, brain death, and altered terminal cardiac activity, and these timings were positively corrected with duration of bradycardia (observed in response to both treatments). In later work, Caputo et al. (2013) showed that the diving reflex was initiated in ducks when immersed in foam or water, which has implications for the use of water-based foam since the apnea and bradycardia induced will prolong the time to unconsciousness and death during culling. Benson et al. (2012) reported that water-based foam resulted in equivalent physiological outcomes in broilers, turkeys, and laying hens and Rankin et al. (2013) also showed that low−medium expansion foam was an effective culling method for adult tom turkeys.

The USDA allows the use of air-filled low−medium low expansion foam to depopulate floor-reared poultry under certain conditions including control of infection with a potentially zoonotic disease, to deal with outbreaks that cannot be contained by conventional depopulation and to kill birds in structurally unsound buildings that would be hazardous for human entry, such as those affected by a natural disaster. A clear advantage of foam is that it may be used in a variety of housing types including open sided and naturally ventilated barns as well as damaged buildings. In the field, generating low−medium foam with gas adds complexity and logistical challenges (Alphin et al., 2010) and does not appear to be justified by improvements in effectiveness or welfare outcomes. Thus this method is not constrained by gas availability or technical knowledge. However, the application of water-based foam has still been described as “resource intensive” and it requires large volumes of water (Benson et al., 2012). Foam is associated with improved biosecurity during and following culling since the foam could be antiviral, there is reduced contact between birds and personnel and the foam traps dust and particles inside the house (Benson et al., 2012). Killing birds with foam is also compatible with in-house composting and several fire-fighting foams (designed to be used in forest fires) meet biodegradability requirements (Benson et al., 2007).

Detailed welfare assessments in a range of species have shown that immersion in low−medium expansion foam results in hypoxia leading to unconsciousness, terminal convulsions, brain death, and eventual cardiac arrest (Benson et al., 2012). Direct comparisons with other depopulation methods (especially gas-based approaches) are problematic as there are variable delivery rates and concentrations involved depending on methods used. However, where available, EEG data for water-based foam killing suggest that consciousness while immersed is not prolonged and is in the same range as gas-based depopulation methods. Importantly, application of foam affects only those birds that are immersed, so there is no gradual exposure to gas as with WHG. This allows the depopulation of large flocks of birds to be tackled in stages while neighboring birds remain unaffected. However, low–medium expansion foam cannot be used in cage houses or other three-dimensional systems because the foam does not build up sufficient height to cover all of the birds.

17.2.4 High expansion gas-filled foam

High expansion gas-filled foam (also known as "dry foam") was developed in the United Kingdom in response to welfare concerns regarding low–medium expansion foam and because there was a desire to facilitate the use of inert gases in whole house depopulation. As discussed previously, inert gases such as nitrogen and argon cannot be used in conventional WHG because of the practical impossibility of sealing the house to the extent required to adequately reduce oxygen levels. The use of high expansion gas-filled foam containing an inert gas allows killing with these gases since the foam envelops the bird, displacing oxygen in the immediate environment. Thus the mode of action of dry foam is effectively as a gas delivery system, since bubbles release gas as they burst due to contact with birds. Raj et al. (2008b) presented preliminary results on high expansion foam filled with nitrogen or air, and showed that the nitrogen-filled foam caused rapid death (the oxygen concentration in the foam was less than 1%). Birds immersed in dry foam made using atmospheric air remained live and conscious until the end of the test period and this finding, along with postmortem investigations, conclusively demonstrated that this type of foam does not cause respiratory obstruction. To investigate this promising technique further, Gerritzen and Sparrey (2008) applied CO_2-enriched high expansion (300:1) foam to six laying hens in a test box. The foam filled the box within 30 seconds, and while two out of six birds tried to escape during the application of foam, no other aversive reactions were seen. Convulsions were observed 20–30 seconds after immersion and were assumed to indicate loss of consciousness. Cessation of cardiac activity occurred after approximately 3 minutes. Based on pathological and physiological data, the authors concluded that CO_2-filled high expansion foam had the potential to be an acceptable method of killing.

McKeegan et al. (2013) carried out a comprehensive study in which broilers, ducks, turkeys, and hens were exposed to N_2-, CO_2-, or air-filled high expansion foam under standardized conditions while their behavioral and physiological responses were monitored. This work employed a specially designed small scale gas-foam delivery system with similar specifications to that which would be used in the operational disease control situation with regard to expansion ratios, surfactant type, temperature of delivery, speed of delivery, method of gas delivery, bubble diameter, and bubble composition. The results showed that humane euthanasia could be achieved for individual birds with both anoxic (N_2-filled) and hypercapnic

(CO_2-filled) foams. In both cases, the mode of action was anoxia and postmortem examination again confirmed that the foam did not occlude the airway. Initial behavioral responses to foam were unremarkable but included headshakes and brief bouts of wing flapping, followed by loss of posture and then vigorous wing flapping characteristic of anoxic death. In agreement with Raj et al. (2008b), immersion in air-filled high expansion foam had little effect on physiology or behavior. Both N_2- and CO_2-filled foam induced pronounced bradyarrythymia and characteristic changes in the appearance of the EEG were used to determine an unequivocal time to loss of consciousness in relation to submersion. The average time to loss of consciousness was 30 seconds in hens and 18 seconds in broilers exposed to nitrogen-filled foam, and 16 seconds in broilers, 1 second in ducks, and 15 seconds in turkeys exposed to CO_2-filled foam (though note that escape of CO_2 around the foam before immersion affected these timings). These trials provided evidence that euthanasia achieved with anoxic foam is humane, rapid and highly effective, due to low oxygen concentrations ($<1\%$) inside the foam.

Although this work provided convincing proof of principle that high expansion gas-filled foam could be used as a depopulation technique, it was noted that convulsive wing flapping had a significant destructive effect on the foam, which is more fragile than low–medium expansion foam due to larger bubble size. The work showed that the height of foam achieved above the birds prior to wing flapping onset was a critical factor in the effectiveness of the approach. High expansion foam does not "flow" as readily as low–medium expansion foam, and early field trials suggested that the forward speed and depth foam "bow wave" as it covered the birds would need to be controlled to ensure a reliable cull. Further research (McKeegan et al., unpublished) was carried out to refine the approach and make its practical application in disease control situations a possibility. N_2-filled foam was used because it was associated with fewer potentially negative behavioral responses (headshaking and hyperventilation) before submersion (McKeegan et al., 2013) and produced better quality, more consistent foam, and also because there was a desire to develop approaches that would reduce demand for CO_2 during disease outbreaks. Large groups of birds (192–360) were exposed to nitrogen-filled foam at 40 or 50 kg/m^2 and in different pen configurations, and EEG and ECG responses were monitored in a subset of birds. The quantity and depth of foam delivered was sufficient to keep the birds covered during wing flapping to ensure a rapid euthanasia. The stocking density of the birds did not greatly affect the foam destruction rate, although gradual movement of the birds away from the approaching foam meant that the actual stocking density at the time of submersion was maximal. Patterns of behavioral change and onset of changes in EEG and ECG characteristics closely matched those previously observed in individual bird trials, and the work produced reliable procedures for the large-scale application of gas-filled high expansion foam.

High expansion gas-filled foam shares the biosecurity and practical advantages of low expansion foam, and birds near the leading edge of the foam are unaffected until submerged, which means that poultry houses can be tackled in sections reducing the risk to welfare of a technical failure. The structural properties of high expansion foam allow it to build up to much greater heights than low–medium expansion

Figure 17.1 Photograph showing the delivery of nitrogen-filled high expansion foam to cull broiler chickens in the United Kingdom. The cull was required due to the rearing building becoming structurally unsafe following a roof collapse.
Source: Photo credit D. Beckett/J. Sparrey, Livetec Systems Ltd., United Kingdom.

foam, opening up the possibility of its use in nonfloor reared birds and in three-dimensional housing. Limited trials suggest that high expansion foam will also penetrate cages (J. Sparrey, Personal Communication). From a welfare perspective, high expansion anoxic foam is preferable because it acts more quickly to induce unconsciousness than low–medium expansion foam and indeed other gas-based depopulation approaches. It is technically demanding however, and knowledge of gas delivery and foam generation is required for successful deployment. Liquid nitrogen can be vaporized more easily and rapidly than carbon dioxide, so development has been in this direction. A full scale nitrogen-based high expansion foam system is now part of the disease control contingency in the United Kingdom (Fig. 17.1).

17.2.5 Ventilation shutdown

The term VSD refers to a procedure involving sealing a poultry house full of birds, shutting down the ventilation, and introducing supplementary heat; the aim is to quickly raise the temperature inside the house to 40°C or more within 30 minutes (which is then maintained for 3 hours) (DEFRA, 2009b). Death of the birds is caused by hyperthermia, whereby their core temperature rises to a fatal level (approximately 45°C). For VSD to be effective the temperature in the house must rise to 40°C or greater and remain at that level; maintaining a relative humidity of at least 75% is expected to speed up the onset of death through hyperthermia (DEFRA, 2009a). For ethical reasons, experimental trials on VSD have never been carried out, but the results of modeling show that in optimum conditions for VSD, the time taken for 2 kg broiler chickens to reach a lethal core body temperature is 35 minutes. For day old chicks, the lethal core body temperature would be reached in 40 minutes (DEFRA, 2009a). The UK Government announced they would allow the use of VSD in extremis in 2006, following advice from the Farm Animal Welfare Council that VSD could be used as a method of last resort. In the United Kingdom, VSD can only be used to kill poultry during an HPAI outbreak where the Secretary of State is satisfied that another method cannot be used. All other permitted killing methods must be explored and discounted (including containerized gassing units, WHG, electrocution, lethal injection, percussion killers, and foam) and there needs to be “serious and heightened concern over human and animal health” before the method would be considered (DEFRA, 2009a). If it is possible to use another method to kill birds immediately “no further consideration should be given to the use of VSD” (DEFRA, 2009a). UK ministers have also stated that VSD would not be used unless resources are stretched beyond capacity, e.g., as a result of multiple outbreaks (DEFRA, 2009a).

These controls are in place because VSD is associated with very serious welfare concerns, primarily because death caused by hyperthermia is associated with significant suffering (e.g., Mitchell and Kettlewell, 1998), and the time to death is prolonged. The time to death estimated by modeling (35−40 minutes depending on bird size) does not take into account the time taken to reach high ambient temperature (30 minutes is aimed for) during which time the bird will be suffering from heat stress. The reliability of the method can also be called into question, because over time as birds die, the heat generation in the house will diminish, making further deaths less likely (or more prolonged). No data on this effect are available due to the lack of field trials. Although sick birds infected with HPAI may have increased susceptibility to heat stress (hastening their death), disease control plans usually also involve killing healthy birds in a protection zone around the outbreak. The UK’s Royal Society for the Protection of Animals (RSPCA) is strongly opposed to the use of VSD, claiming that “with proper planning, ventilation shutdown should never need to be used” (RSPCA, 2008). Indeed, the RPSCA legally challenged DEFRA through a judicial review but their claim was not upheld so VSD remains lawful in the United Kingdom, subject to the conditions outlined earlier. DEFRA has produced detailed guidelines on VSD with the aim of minimizing the welfare impact of the process. These include instructions on how to calculate the total supplemental heat requirement based on building properties (DEFRA, 2009a) and guidance on various practical aspects such as heater positioning (DEFRA, 2009b). Following VSD (and once the temperature inside the house has dropped below 30°C) DEFRA advise that staff can enter the house to inspect the birds for signs of life and kill any surviving birds using a permitted method.

In the United States, the USDA revised their policy on permitted methods for mass depopulation for disease control in 2015 to include VSD, to meet a goal for poultry to be depopulated within 24 hours of a positive diagnosis of AI. As in the

United Kingdom, although the USDA consider VSD to be an adjunct mass culling method, their policy is that it should be used only after a full consideration of the disease threat posed and when no other method can be employed in the required time scale (USDA, 2015). In early 2016, VSD was used for the first time to cull chickens and turkeys in an AI outbreak in Indiana, United States. The numbers of birds killed or numbers of VSD procedures carried out are not available, and there are no data to allow a welfare evaluation of the method in practical use. It is not clear why other methods were ruled out in the Indiana outbreak. A USDA spokesperson stated that the cold temperatures (due to the time of year) made the use of water-based foam difficult at some of the ten affected commercial poultry farms, but this does not explain why all other mass depopulation methodologies were rejected. The use of VSD as a mass depopulation method provoked a strong reaction from animal protection groups such as the Humane Society of the United States and Compassion in World Farming (McDougal, 2016), who suggested that the method had been used unnecessarily in the face of better alternatives. It remains to be seen if VSD will become a more widespread approach to emergency killing for disease control, but given its severely negative welfare implications, it is definitely not preferable to other emergency depopulation methods and should remain a method of last resort.

17.2.6 Other methods

Although gas- and foam-based approaches predominate, various other methods of killing have been used to cull poultry in disease outbreaks. Gerritzen et al. (2006) described the use of mobile electrocution equipment consisting of a water bath and a closed-loop shackling line in the 2003 Netherlands AI outbreak. Scheibl (2008) produced a field report on the successful mass culling of ducks with mobile electrocution lines and reported a capacity of 2500 birds per hour. The current applied in these applications was higher than that used for stunning at commercial slaughter, because when using electrocution as a culling method there must be sufficient constant current to cause instantaneous and simultaneous destruction of the central nervous system and cardiac arrest (Galvin, 2005). An advantage of electrocution is that death occurs immediately, but problems were encountered in practical use, such as some birds missing the water bath and not receiving full current (Gerritzen et al., 2006). Another major drawback is that the method requires individual handling of birds (with associated labor costs and biosecurity implications) and live shackling which is associated with welfare issues (Gentle and Tilston, 2000).

Cervical dislocation is considered to be a humane means of killing poultry and is routinely used to cull individual sick or moribund birds in commercial production. It is usually performed manually and requires handling and restraint of individual birds; thus its welfare impact depends largely on the skill of the operator (Galvin et al., 2005). Operator strength may be insufficient to achieve humane and reliable dislocation in larger birds, and operator fatigue is an important consideration when considering the culling of large flocks. In the EU, Council Regulation 1099/2009 restricts killing by manual cervical dislocation to 70 birds per person per day. Though cheap and accessible, cervical dislocation is only really suitable for the depopulation of small groups of birds.

Pharmacological approaches to mass depopulation have also been considered. Overdoses of anesthetic by lethal injection or inhalation have very low welfare costs and are used for euthanasia in other contexts (e.g., veterinary practice). However, they are expensive, require individual handing and restraint, can only be carried out by highly trained operators with appropriate technical skill and knowledge, and use agents that are open to abuse (Galvin, 2005; Galvin et al., 2005) - all of which prohibit their use in large-scale depopulation. The addition of lethal compounds to food or water is an attractive prospect, since it would avoid handling of birds and a method for delivery of water medication is integrated into the structure of many poultry buildings. Previously, alpha-chloralose has been used to sedate poultry in houses prior to killing them by using cervical dislocation, decapitation, or exposure to gas mixtures (Raj, 2008). However, as with many drugs, the bitter taste of this compound prevents the intake of a single lethal dose, and attempts to encourage birds to ingest the drug in sufficient quantity would require withdrawal of food and water for considerable periods prior to the cull, generating welfare concerns. Currently, a suitably effective compound in terms of activity, palatability, safety, and welfare impact is yet to be identified, though this is a poorly studied area and more research on candidate substances is justified.

17.3 Conclusions

There are a range of acceptable mass depopulation strategies which have different strengths and weaknesses in terms of their bird welfare implications, biosecurity risks, flexibility, technical complexity, and cost. Certain methods are therefore best suited to certain situations, and it can be assumed that a combination of approaches is needed to successfully control a major disease outbreak. The need to accommodate different sizes and types of poultry operation and different species of birds will dictate the most suitable approach, and it is impossible to recommend a depopulation technique that will be suitable for all circumstances. Applying a range of techniques also spreads the load on demand for specialized personnel and equipment, and raw materials such as gas. In all cases, the welfare impact of mass depopulation methods is dependent on the competency with which they are administered, and adherence to strict controls and standard operating procedures will minimize animal suffering.

Emergency killing methods are applied against a complicated backdrop of challenges including emotional and physical worker fatigue, potential labor shortages, maintaining worker morale in difficult circumstances, personnel safety, public health risks, and significant time limitations (Kingston et al., 2005). In competition with these other important concerns, animal welfare may (understandably) not always be paramount. However, maintaining acceptable ethical standards is not unachievable and welfare must be carefully considered so that the conduct of authorities is able to withstand public and professional scrutiny (Kingston et al., 2005). Although major disease outbreaks continue to occur and the demand for mass depopulation is increasing, the available evidence suggests that we do have methods which adequately project bird welfare without compromising disease control and public health protection goals.

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Index

Note: Page numbers followed by "*f*" and "*t*" refer to figures and tables, respectively.

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