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Impact of Free-range Poultry Production Systems on Animal Health, Human Health, Productivity, Environment, Food Safety, and Animal Welfare Issues

Since animals were first domesticated, there have been major changes in both the animals and their care. The remarkable changes in poultry production efficiency have been well documented. (Shutterstock photo from Alexius Sutandio.)

Abstract

As farmers in the United States try to develop new poultry operations, there are two main possibilities. The first is to work within the existing vertically integrated systems. The second is to develop independent, smaller operations. Those that choose the second option look toward alternative production systems, such as free-range poultry production. As such, these individuals often find that there is a distinct lack of usable definitions and knowledge, as well as a great deal of confounding research related to this field. The popularity and beliefs associated with what some consider a return to old systems are very strong and have not dissipated. The consumer has worked to fuel this movement toward free-range, organic, or even simply what some consider natural poultry production.

This publication serves to review what is known about poultry egg and meat production with specific attention to available research on free-range production systems. Stressors related to alternatively housed and managed birds, as well as the known advantages and disadvantages for farmers, are reviewed. Food quality and food safety in regard to poultry meat and eggs are often understood by farmers and consumers as one and the same. Clarification of food quality and food safety with regard to poultry

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production systems will be discussed. The role of farming systems in disease control is included in this discussion. Attention to the environmental system, soil contamination, and manure burdens placed on the land by free-range poultry is also considered. This consolidation of information is aimed at helping further the discussion of free-range poultry as it pertains to larger farming systems and the future of this growing field of niche market poultry production.

INTRODUCTION

The domestication of animals for food production has played an important role in the development of agriculture as a whole (Mourão et al. 2006). Since animals were first domesticated, there have been major changes in both the animals and their care. The remarkable changes in poultry production efficiency have been well documented (Havenstein, Ferket, and Qureshi 2003). In the last few decades, the number of eggs a hen can lay each year has doubled and the amount of feed required to produce these eggs has been cut in half (Anderson et al. 2013), resulting in decreased cost to consumers. Similar improvements have occurred in poultry meat production. In 1923, chickens were raised to 16 weeks of age and only weighed 1 kilogram (kg) (2.2 pounds [lb]). The feed efficiency of weight of feed to weight of body weight gain was 4.7. By 2001, chickens were raised to 6 weeks of age and had a live weight of 2.6 kg (5.73 lb). Feed efficiency was improved to 1.63 (Thiruvenkaden, Prabakaran and Panneerselvam 2011).

Despite the ever-increasing separation between farming and the general public, today's consumers are increasingly interested in where their food comes from and how the food is produced. With regard to animal food products, animal welfare, food quality, and sustainability have become key issues because consumers are increasingly concerned with the depictions of commercial poultry production issued by agenda-driven groups online. As a result of consumers' changing perception of animal production systems, there has been an increased interest in *free-range*[1] poultry production. Although presently a small portion of the poultry industry in the United States, there is growing pressure by some consumers to transition from conventionally raised poultry to free-range poultry production with improved animal welfare, improved product quality, and decreased environmental impact cited as justification.

Any discussion on the impact of free-range poultry must begin with a definition of what "free-range production" actually means. Free range and *outdoor access* are two terms that are often confused. In the United States, there are no legal definitions for either term. With regard to poultry production, the term "outdoor access" typically refers to production systems that allow flocks to leave a stationary housing structure. Outdoor access may be provided either continuously or during specified daylight hours. The outdoor area does not require a specified amount of space per bird nor specified environmental enrichments (e.g., grass, shelters, and dust baths), although the birds are able to move about freely and perform natural behaviors. "Free range" is a similar term in that it refers to a system in which poultry have outdoor access, but in the case of free-range production, a shelter or a secured outdoor space (i.e., run) may or may not be provided. As with outdoor access, the outdoor area does not have a specified amount of space per bird nor specified environmental enrichments. Birds are permitted to move about freely and exhibit natural behaviors. There are no stipulations with regard to maximum flock size or type of bird raised.

The terms "pastured" or "pasture raised" are also sometimes used. There are distinct differences between free-range and pasture-related terms. Whereas poultry flocks are kept outdoors in both cases, *pasture* must be provided in the latter. Pasture is defined as a tract of land covered with grasses, legumes, brassicas, or other forages suitable for grazing by livestock. In the case of pasture poultry, the pasture is maintained specifically for ingestion by poultry, for the rotation of poultry after another livestock species, or for use in a mixed crop-livestock program with harvest of a forage crop. The flock may be maintained in housing structures that are either mobile or stationary. Bottomless, moveable pens have become

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[1] Italicized terms (except genus/species names and published material titles) are defined in the Glossary.

popular in the United States. The birds are kept in the pens, which are moved on a regular basis, giving the birds access to fresh pasture. If allowed to run free, natural shade or man-made shelters may be incorporated into the pasture system to protect the birds from extreme weather conditions.

In the United States, "free range" is often mistakenly interchangeably used with "natural," "*free roaming*," "*cage free*," and at times "organic." "Cage free" or "free roaming" are terms typically used in reference to egg production and are simply defined as a housing system in which poultry are not maintained in cages. Outdoor access is not a requirement, and environmental enrichments may or may not be provided. Birds are permitted to move about freely within the confines of a poultry house, however, and exhibit natural behaviors. The U.S. Department of Agriculture (USDA) defines "*natural*" as a product with no artificial ingredients or added colors and minimally processed. "*Minimal processing*" means that the product was processed in a manner that does not fundamentally alter the product. The label must include a statement explaining the meaning of the term natural (such as "no artificial ingredients"; "minimally processed"). According to the USDA definition, "natural" poultry may be kept in free-range, organic, pasture, cage-free, or caged systems. The term "natural" is different from "naturally raised." "Naturally raised" refers to live animal production practices and previously fell under a USDA Agricultural Marketing Services (AMS) voluntary marketing claim standard for which USDA provided third party verification. In 2016 AMS withdrew "naturally raised," as well as "grass fed" labeling standards, noting that it does not have the ability to define the standards for these terms.

In order to be sold as certified organic, the National Organic Program Final Rule Section §205.236 requires that poultry or edible poultry products be from poultry that have been under continuous organic management beginning no later than the second day of life. All agricultural components of the feed ration must be 100% organic. All poultry must have access to the outdoors. Fields, including pastures or lots used for outdoor access, must be certified organic. Organic poultry producers may provide temporary confinement or shelter in specific instances. There are no current space requirements in the American organic standards for poultry. In January 2017 new space requirements were proposed, but they were officially withdrawn in May 2018. The rule would have given specific space requirements for both meat- and egg-producing chickens based on age and housing system.

The European Union (EU) has more specific definitions for the term free-range poultry (CEC 1991) than does the United States. For table egg production, there are four general categories: organic, free range, barn, and cage (CEC 2002). The regulations include specific conditions that must be met in order for a flock to be considered free range. Poultry must have continuous daytime access to open-air runs, except in the case of temporary restrictions imposed by veterinary authorities, as in the instance of an avian influenza (AI) outbreak. The open-air runs must be mainly covered with vegetation and not used for other purposes except for orchards, woodland, or livestock grazing. The EU regulations provide specific housing and outdoor area density regulations. There must be a minimum of 4 square meters (m^2) (~45 square feet [ft^2]) of outdoor access per hen. The open areas cannot extend beyond a radius of 150 m (~500 ft) from the nearest pop-hole of the building, although an extension of up to 350 m (~1,150 ft) is allowed provided that a sufficient number of shelters and drinking troughs are evenly distributed throughout the whole open-air run, with at least four shelters per hectare (~1.6/acre).

For poultry meat production, the EU Council Regulations state that there are three forms of free-range poultry including "free range," "traditional free range," and "free range total freedom" (CEC 2008). In a "free-range" system, the stocking rate in the house and the age of slaughter are similar to those for barn-reared poultry. The birds must have had continuous outdoor access to open-air runs for at least half of their lifetime. In addition, the open-air runs must be mainly covered by vegetation. The total amount of pop-hole length should equal at least 4 m per 100 m^2 (12 ft per 100 ft^2) surface of the house. The feed used in the fattening stage must contain at least 70% cereal grains. For "traditional free-range" production systems, the stocking densities are slightly lower but the total usable area of the poultry houses at any single production site may not exceed 1,600 m^2 (~17,250 ft^2). There are limitations on flock size, and the birds must be of a strain recognized as being slow growing. To be considered slow growing, they must have a body weight gain of less than 50 grams (1.76 ounces) per day. The amount of open-air access is also increased. For "free-range total freedom" production systems, the criteria set for traditional free range are the same except that the birds must have continuous daytime access to open-air runs of unlimited area.

In both Europe and the United States, the number of farms with free-range or organic poultry production is small. France is an exception in that a large number of farms are involved in alternative chicken meat production. This would include the Label Rouge chicken meat production system. Label Rouge, which is French for "red label," is a sign of quality assurance in France as defined by Law No. 2006-11. Label Rouge certifies that a product has a specific set of characteristics. In the case of chicken meat, a certain breed is required and grown to at least 81 days of age. The chickens must be allowed access to free range, and the carcasses are air chilled. No statistics are available on the number of alternative meat chickens (i.e., organic and/or free range) in Europe and the United States. Estimated market share of alternative chicken meat production in Europe is only 5–10% (van Horne and Bondt 2013). It is probably much lower in the United States, which has a larger conventional chicken meat production system. There is no official reporting system for free-range poultry production in the United States. According to the USDA–AMS June 4, 2018, cage-free shell egg report (USDA–AMS 2018), there were almost 54 million cage-free egg layers in the United States during the month of May 2018. This represents 14% of all the table egg layers in the country (USDA–NASS 2018). This would include both confined and free-range production systems. Of the cage-free hens, almost 16 million were certified organic, which would have access to the outdoors. This would represent only 0.3% of the total hen inventory for May. Organic, however, is only a portion of the free-range hen production in the United States. There currently is no database specific for only free-range table egg producers in the United States.

Consumers, egg producers, state legislatures, and consumer advocate groups, along with the animal rights organizations, are taking on and claiming a vested interest in how eggs are produced. Egg producers have always worked to provide products to meet consumer demands. In Europe, however, these production system changes have been driven by environmental and consumer advocate groups, which culminated in the 2012 ban on the use of conventional cages in egg production (European Commission 1999). In the United States, California voters passed Proposition 2 (2008) which defined the housing conditions for laying hens starting in 2015 (California Health and Safety Code 2009). In the 2016 election, Massachusetts voters passed similar legislation for changes in housing conditions by 2025. These laws and legislative actions have been promulgated and passed with little understanding of the implications on animal well-being and the safety of the products they produce (Anderson 2009).

While many perceive improved animal welfare with free-range production systems, the use of outdoor access has some inherent risks related to food safety, animal health, biosecurity, productivity, and environmental impact. This report will detail the animal welfare, food safety, animal health, biosecurity, productivity, and environmental impact of free-range poultry. There is an ongoing debate as to whether or not poultry products from free-range production systems are more likely to be contaminated with major foodborne bacteria such as *Salmonella* and/or *Campylobacter* than those from conventional, indoor production systems. Avian influenza is a global threat to public health and can cause large economic losses to commercial poultry industries. The 2003 outbreak in the Netherlands (potentially introduced by wild fowl to a free-range laying hen farm) resulted in the culling of 30 million chickens and 87 human cases. Productivity of free-range poultry will also be discussed. For example, the production cycle is longer for free-range poultry meat production compared to conventional indoor systems. As a result, feed consumption and manure production per bird can be expected to be higher in the free-range systems. This, in turn, can have a major impact on the environmental burden related to free-range production.

ANIMAL WELFARE

The assessment of animal welfare for poultry flocks reared under different production systems is complicated and, at times, controversial. There are considerable differences regarding what constitutes acceptable animal welfare, how welfare status should be measured, and the interpretation of research results. The comparison between different housing systems is complicated because of the fact that management, nutrition, and breed vary among the different housing systems used. In addition, behavioral changes as birds adapt to a management system can mask any welfare concerns. As a result, while the presence of a specific behavior may effectively identify poor welfare, its absence is not evidence of good welfare.

Comparisons of poultry production systems also must examine the effects of flock size in addition to the housing system used. Chickens naturally live in small groups and establish a pecking order within their group. This is presumed to involve serial aggressive interactions. The individual birds remember the result of these interactions and the hierarchy becomes established. In larger flocks, this system breaks down because the hens are only able to identify a limited number of individuals. In such cases, the hens adapt by becoming less aggressive and changing their social system to one in which dominance is determined through direct assessment of "status signaling," which can include comb size and postural clues, rather than the remembered individual assessment used in a small group pecking order (D'Eath and Keeling 2003).

The basic measure of animal welfare is physical health. It is uniformly agreed that injury, disease, and deformities result in poor animal health and welfare. A whole host of factors can affect disease incidence, and the production system used will impact many of these. According to the Danish Poultry Council, 17.1% of the hens died in the production period in organic systems, which includes outdoor access, while 5.4% and 12.1% died in cage and deep litter systems, respectively (Eigaard et al. 2003). Research has shown, however, that laying hens that used outdoor areas had lower plumage damage and a lower incidence of footpad dermatitis (Rodriguez-Aurrekoetxea and Estevez 2016). In comparison, hens that walked long distances indoors showed a higher incidence of footpad dermatitis. Yilmaz Dikmen and colleagues (2016) also reported reduced foot lesions in free-range systems compared to conventional or enriched cages.

Modern strains of egg layers can frequently suffer from structural bone loss as a result of the large calcium demand with the high levels of egg production. Regmi and colleagues (2016) examined the bones of hens at the end of their laying cycle, comparing different strains and housing systems. They concluded that range and cage-free housing may have benefits on bone integrity compared to conventional cages, but the improvement is not enough to prevent fractures or keel bone deformities.

If animal welfare encompasses more than simply animal health, as it does for most consumers, the problem becomes how to assess the "psychological health" of nonhuman animals. This issue has been debated for more than 20 years, and the only consensus is that no single measure of animal welfare is adequate. Although it is accepted that several different measurements are necessary, there is no consensus regarding which combination of measures should be used. Individual measures that include physiological, biochemical, and behavioral factors can be used, but they may result in contradictory conclusions.

The effect of stress on physiological measures, including heart rate, body temperature, respiratory rate, increases in adrenal secretion and corticosteroids, and depression of immune function, has been widely studied in poultry (Puvadolpirod and Thaxton 2000). Stressors in chickens result in increased circulating concentrations of corticosterone (Scanes 2016). Corticosterone influences the *heterophil*:*lymphocyte* (H/L) ratios, and such shifts can be used as markers of stress. Yilmaz Dikmen and colleagues (2016) reported that H/L ratios were highest in birds in conventional cages compared to enriched cages and free range. The use of such parameters, however, has had conflicting results, with the levels obtained varying as a function of how the birds were handled. In addition, obtaining these measurements itself can be stressful and at the same time not practical at the production level.

Since physiological responses are difficult to precisely measure under field conditions, animal welfare research has focused primarily on behavioral responses. Yet, there are inherent difficulties with interpreting such data. Interpretation of behavioral data when evaluating different housing conditions is complicated. Animals can become acclimatized or adapted to their environment. There may be genetic differences between the strains used in the housing conditions. Behavior may also be dependent on external stimuli, such as antipredator behavior, that may not be present in both systems.

In order to determine what constitutes normal behavior of chickens, time budgets were developed for semi-wild jungle fowl kept in a zoo (Dawkins 1989). During the active part of the day, jungle fowl spent 60% of their time ground pecking and 34% ground scratching. Although the chickens were fed regularly, they still spent most of their time on foraging behaviors. Housing systems in which chickens are not able to forage would, therefore, prevent them from performing what can be perceived as a natural behavior.

Vocalizations have been suggested as a measure of animal welfare, with the major challenge being how to interpret the meaning of a noise emitted during a specific circumstance. Approximately 30 distinct vocalizations from both young and adult chickens have been detected (Wennrich 1981). A comparison of two lines of laying hens noted distinct differences in the vocalization of the hens during a feed restriction stress. This would indicate that the response of a flock to a stress may be related to genetics (Zimmerman and Koene 1998). For one strain of laying hens there was an increase in the level of alarm calls as an indicator of frustration due to the lack of a reward in a situation that previously was consistently rewarding. Alternatively, for a different strain more gakel-calls and increased locomotor activity were some common indicators of frustration.

Some researchers have divided animal welfare factors into two groups—aversion and deprivation. Aversion would refer to stress resulting from conditions that an animal is motivated to avoid. Deprivation refers to a condition in which an animal is unable to complete a behavior it is motivated to do. This may result from a physical restraint or the lack of suitable stimuli. A fundamental question raised here is how are an animal's "needs" determined? Two test types have been used in the past. In preference tests, animals are offered choices between alternatives to see which one they prefer. In operant conditioning, the animal is trained to make some response to gain access to or to avoid certain consequences. This can be pecking a key or pressing a lever. Such methods have been used to determine animal responses to different flooring types, different cage sizes, different temperatures and light levels, and many other factors (Dawkins 1988).

Laboratory tests measuring the choice and preference of an animal for different "wants," such as floor types, perches, nest boxes, dust bathing, etc., may or may not be applicable at the farm level. It is important to watch the animals in situ. For example, in some free-range broiler systems many chickens do not leave the house and, if they do, do not venture far from the house. One could conclude that chickens do not want to go outside. It could be, however, that the outdoor area is not providing the ranging habitat that suits their natural behavioral needs. Research has shown that chickens are attracted to trees and are more likely to venture outside a house if there are trees or shrubs in the outdoor run (Dawkins et al. 2003; Fanatico et al. 2016).

Fear is defined as an emotional state that arises from negative stimulus leading to behavioral and physiological changes that help the animal to cope with the stimulus. Traditionally, this has been assessed by the duration of tonic immobility reaction and H/L ratio. Long durations of tonic immobility are believed to be indicative of high levels of fearfulness. Increases in avian basophils and heterophils have been associated with stress. Interestingly, results from studies suggest that frequent movement between indoor and outdoor areas was associated with indicators of fearfulness (Mahboub, Müller, and von Boreel 2004). Whereas increased time outside of the house was associated with decreased feather pecking (Bestman and Wagenaar 2003; Mahboub, Müller, and von Boreel 2004), it was also associated with an increase in other stress indicators. In contrast, Hartcher and colleagues (2016) studied tonic immobility to assess the welfare of laying hens on range. They used radio frequency identification (RFID) to identify the top 15 and bottom 15 hens for range use as determined by the time spent on range over a 13-day period. Hens that spent the most time outside displayed a decrease in fearfulness. Similarly, hens that spent less time outside had higher tonic immobility durations, indicating higher levels of fearfulness.

A computer model was developed to assess the welfare of laying hens housed in different production systems (De Mol et al. 2006). The European model used 25 attributes, each with two or more levels, defining the characteristics of a production system. Each attribute was given a weighted factor based on the available scientific knowledge of the effects of the attribute levels on the welfare aspects. Based on the model, the factors of feeding level, space per hen, perches, water availability, and nests were the most important attributes. The attribute of free range was of minor importance. In regard to the welfare assessments, however, the computer model concluded that cage systems scored the lowest, barn and aviary systems intermediate, and European organic systems scored the highest.

A different protocol was developed for assessing the welfare of laying hens in free-range production systems, examining both physical and emotional elements (Whay et al. 2007). This protocol was then used to investigate the effects of different approaches to housing and management on the welfare of the hens. Measures of the hens' attitude included arousal, noise, flight distance, and response to a novel object. Measures of activity included feather pecking, aggression, and use of range. Physical welfare was measured by mortality, body condition, and egg quality. In the study, there were five visits to each of 25 egg production units. Estimated losses, which included deaths and culls, ranged from 1.8% to 21.5%, with a median value of 6.95%. The distribution of the mortality numbers was skewed by a small number of farms with heavy losses. As a result, the median value provides a more representative indicator. No facility features were identified as having a significant effect on mortality, but the absence of perches altered hens' attitude, activity, and performance, suggesting that the welfare of hens was decreased when they were housed on plastic floors without perches.

More recent research has indicated a possible link between stress and eggshell irregularities (Alm et al. 2016). Nest deprivation in laying hens has been shown to increase fecal levels of corticosterone metabolite as well as corticosterone concentrations in yolk. These levels were found to be positively correlated with increased incidences of eggshell irregularities. This would suggest that the incidence of eggshell irregularities may be a noninvasive welfare indicator.

In a Danish study, the outdoor area use of 18 egg production flocks ranging in size from 1,200 to 5,000 hens was evaluated. Hegelund, Sørensen, and Hermansen (2006) found that the outdoor area use ranged from 7% to 38% of the flock, with an overall mean of 18%. The majority of the hens that did go outside stayed close to the hen house. Mortality ranged from 9% to 62%, with high mortality partly due to outbreaks of *Pasteurella multocida*. In some flocks, predation and piling were important causes of mortality. As would be expected, keeping poultry outdoors exposes them to predators. In many cases, ground predators can be controlled with an electric fence, but predation by birds of prey is more difficult to control. Providing natural shelters, like bushes, or artificial roofs can decrease aerial predation (Berg 2001). Weeks, Lambton and Williams (2016) also reported high variability in mortality associated with free-range egg laying flocks. Cumulative mortality at 60–80 weeks of age averaged 10% but ranged from 0 to 69.3%. More research and training are needed to improve production in commercial free-range systems.

When comparing conventional cages, furnished cages, noncage (floor) systems, and outdoor systems, the main conclusion was that no single housing system can be identified as being ideal for hen welfare (Lay et al. 2011; Widowski et al. 2016). Each system has its own merits and challenges. Cage systems, which limit hen movement, can result in problems with osteoporosis. On the other hand, floor systems can result in more bone fractures (Regmi et al. 2016). Although more space allows the hens to perform a wider repertoire of behaviors, it also includes an increase in detrimental behaviors such as feather pecking, cannibalism, and piling. Production systems in which hens are exposed to litter and/or soil provide greater risk for disease and parasites. Thus, although the perception may be that animal welfare is increased in free-range production systems, this may not be the case with all operations. More research is required to determine what constitutes good animal welfare, how welfare should be measured, and which production system best meets these welfare needs.

When compared with barn systems for laying hens, providing an outdoor run can lead to higher space allowances, an increase in the number and types of behavioral and physiological stimulations, and the freedom to move between different environments with changes in climatic conditions and bird preferences (Knierim 2006). Based on these criteria, one can assume that there is an increase in animal welfare. Knierim (2006) noted, however, that outdoor runs are also associated with increased risk factors that have the potential to adversely affect hen welfare. This included increased contact with infectious agents, greater difficulties maintaining hygienic standards, increased possibilities of unbalanced diets, and increased threat of predation. Management factors recommended to limit these risks included restricting group size, keeping cockerels with the hens, rotating runs, and providing well-dispersed covers. Additional recommendations included appropriate pullet rearing and breeding strategies. The limited amount of research involved in resolving problems encountered in free-range systems makes it difficult to make a final judgment on the welfare aspects of outdoor access compared to completely indoor facilities (Knierim 2006).

Although there have been several studies comparing the welfare status of laying hens in different management systems, there are only a few looking at meat poultry, with very few focusing on turkeys. Dawkins and colleagues (2003) studied the factors that affect range use of commercial free-range broilers in England. They reported that few broilers range in winter, but, even in summer, the maximum number of chickens observed outside during daylight hours at any one time was less than 15% of the flock. Taylor and colleagues (2017a) tracked the ranging behavior of 300 individual broilers from each of four flocks in two seasons on a commercial farm in Australia. They found that there was considerable variation between flocks. Chickens that never accessed the range varied from 13% to 67% of the tagged individuals. Those using the range infrequently ranged from 15% to 44% and accounted for less than 15% of all the range visits. High-ranging chickens varied from only 3% to 9% and accounted for 33% to 50% of all range visits. As expected in this Australian study, daily frequency and duration of range use was greater for summer flocks (Taylor et al. 2017b).

Behavioral observations are already used in the clinical assessment of animal health for meat poultry, as in the case of gait scores to assess the leg health of broiler chickens. Such assessments do not identify the underlying problem, but gait scores give a convenient on-farm assessment of leg health. Škrbić and colleagues (2014) compared the performance of Redbro broilers raised to 81 days of age in either a confinement or a free-range system and reported that those broilers reared in the free-range system had a decrease in the number of chickens with footpad dermatitis as well as a decrease in the frequency of associated lesions. In contrast, Castellini and colleagues (2012) reported higher incidences of severe foot and breast lesions in organic systems than in conventional indoor production. Both systems used the same strain of fast-growing chickens, leading the authors to conclude that the fast-growing chicken strains are not well suited to the organic system and their welfare is worse in organic systems than in conventional indoor. Foot and breast lesions were not noted in the slower-growing chickens in the organic-plus system.

Knierem and colleagues (2007) used the latency-to-lie test to evaluate leg problems in broilers raised in organic or conventional systems. The shorter the time to lay down, the more likely they are to have leg problems. The latency-to-lie test showed less leg problems for those raised in organic conditions. The changes are most likely due to differences in the genetics of the broilers reared in the two production systems. They found no difference in tonic immobility (the longer the time, the more fearful the birds), breast condition, and foot pad condition between the two systems. Durali and colleagues (2014) used RFID to evaluate the level of range of specific broilers in a commercial free-range flock. They found that level of range use had no effect on latency-to-lie time.

As with laying hens, providing meat birds with outdoor access leads to increased space allowances, an increase in the variation of behavioral and physiological stimulations, and the ability to move between different environments. Research shows, however, that the use of outdoor access is limited with meat birds; therefore, evaluation of the impact of the range use on the welfare of meat birds is difficult.

The use of moveable, bottomless pens on pasture may provide outdoor access while limiting some of the negative aspects of free-range production, such as predation and exposure to wild birds. Additional research is needed in the animal welfare status of birds reared in this type of production system. In one study, using fast-growing meat chickens kept in hoophouses in the summer (Moyle et al. 2014) had to be terminated early because of extreme heat. It is important to develop portable houses that are able to deal with weather fluctuations, especially in areas with high summer temperatures.

FOOD QUALITY

The popular literature addressing the effect of free-range production systems on food quality is contradictory and can be confusing to consumers, with different sides of the debate selectively referencing studies supporting their side. Many different factors need to be considered when comparing food quality between production systems.

Eggs

Many consumers perceive eggs from hens kept in free-range production systems as being nutritionally superior to those produced from hens in cages. What the hens eat is more important than whether or not they go outside. The type of feed and pasture composition are important considerations in addition to the management of the pasture itself (Horsted, Hammershøj, and Allesen-Holm 2010). Anderson (2011) reported that eggs from “range-reared” hens had more total fat, including higher levels of unsaturated fats such as omega-3 fatty acids. Karsten and colleagues (2010) reported that, compared with eggs from caged hens, eggs from “pastured” hens contained twice as much vitamin E and long-chain omega-3 fatty acids, two-and-a-half times as much total omega-3 fatty acids, and half the ratio of omega-6 to omega-3 fatty acids. As with Anderson (2011), Karsten and colleagues (2010) reported no differences in vitamin A levels. There was no effect of range production system on cholesterol levels. Mugnai and colleagues (2014) also reported significant decreases in omega-6 and higher omega-3 fatty acids. Eggs from hens on a grass-clover pasture and fed a traditional layer diet had less favorable scores in several sensory quality attributes compared to hens in an indoor system. Based on the omega-3 content, the research would support the belief that eggs from hens on pasture were nutritionally superior to eggs from hens in cages, although taste may be adversely affected. This is related to their diet and not whether or not the hens were outside.

Meat

As with the egg, the popular literature describing the effect of pasture on performance, carcass composition, and meat quality has been contradictory. The quality of chicken breast meat produced in the United Kingdom (UK) from conventional and free-range systems was compared by Brown and colleagues (2008). The breast fillets from the chickens raised in the conventional system were rated as being more tender and juicy, but no significant differences in chicken flavor were detected. Givens and colleagues (2011) found no evidence that meat from free-range chickens had a fatty acid profile that would be classified as healthier than that of intensively reared birds. Free-range breast and leg meat contained significantly less polyunsaturated fatty acids (both omega-6 and omega-3) and higher omega-6/omega-3 ratios. Dal Bosco and colleagues (2016), however, showed that grazing improved the nutritional value of meat by increasing the omega-3s and decreasing the omega-6/omega-3 ratios. Meat from the outdoor chickens also had higher levels of antioxidants. This was mainly due to the higher levels of tocopherols and tocotrienols. Despite the higher oxidant protection in the drumstick, the thiobarbituric acid reactive substances (TBARS) were higher. The authors hypothesized this is because of the higher kinetic activity of the chickens and the higher percentage of polyunsaturated fatty acids. They recommended strategies to decrease activity in the last days of rearing.

Castellini, Mugnai, and Dal Bosco (2002) reported that organic chickens had carcasses with higher breast and drumstick percentages and lower levels of abdominal fat. The muscles had lower pH and water holding capacity. The organic chicken meat also had higher cooking loss, lightness values, shear values, iron, polyunsaturated fatty acids of the omega-3 series, and higher TBARS. The sensory quality of the breast muscle from organic chickens was reported to be better. The reasons for the conflicting results are unclear but would most likely be related to the quality of the forage material in the outdoor areas.

Stadig and colleagues (2016) compared slow-growing broilers raised indoors or with outdoor access to 70 days of age. The outdoor access was either on grassland with artificial structures or on an area being used in short-term rotation coppice with willow trees providing shelter. Those chickens with the willow trees used the range more and ranged further than those with artificial structures. Although those chickens raised indoors were larger at harvest, there were no statistically significant differences in feed consumption or feed efficiency. Breast fillets of chickens with free-range access were darker and yellower than those raised indoors. There were no differences in fat, protein, moisture, or ash content, but chickens on range had higher levels of unsaturated fatty acids. A taste panel found no differences in taste, color, appearance, or aroma of the meat. The taste panel found the breast meat from those chickens with the willow trees, and thus the most range use, to be more tender and less fibrous compared to the chickens on grassland with artificial shelters and those chickens raised indoors. In addition, the meat from the chickens with the willow trees was juicer than that of the indoor chickens. Overall, free-range access negatively affected slaughter weight, but positively affected meat taste or composition.

A meta-analysis of the literature noted such inconsistencies among research reports (Sales 2014) and concluded that the consumer preference for meat from free-range poultry is not justified by the research. Instead, it would be preferred to identify factors that do positively affect meat quality. Breed, slaughter age, and feeding strategy all have major impacts on the sensory profile of chicken meat (Horsted, Allesen-Holm, and Hermansen 2010).

Pasture composition can have a major effect on meat quality. Dehydrated pastures (which included Italian rye grass [*Lolium multiform*] and balansa clover [*Trifolium michelianum*] harvested in the flowering state) in the diet of broiler chickens significantly decreased ratios of saturated to polyunsaturated fatty acids (Mourão et al. 2008). In addition, leguminous pasture intake has been shown to decrease the ratio of omega-6 to omega-3 fatty acids in breast meat. Ponte and colleagues (2008) observed decreases of the omega-6 and omega-3 precursors' linoleic acid and alpha-linolenic acid (ALA) in breast meat. In spring, the levels of eicosapentaenoic acid (EPA) in the breast meat were higher, suggesting a greater conversion of ALA into EPA in these chickens. Ponte and colleagues (2008), however, showed that broilers on pasture consumed less than 5% of the daily intake of dry matter (DM) from pasture.

Outdoor access was shown to have no effect on growth performance of a slow-growing breed, but the appearance and meat quality of the chickens was improved. In addition, giving outdoor access beginning at 36 days of age appeared to be more beneficial than providing outdoor access beginning at 71 days of age (Chen et al. 2013).

Although research directly comparing the attributes of pasture-fed to conventional chicken meat has indicated some nutritionally significant differences, the differences are very much diet specific and may not be carried through to the market place. In a survey of organic, free-range, and conventionally produced chicken purchased in the market place, there were no differences in the protein content, fatty acid composition, and sensory properties between free-range and conventionally produced chicken (Husak, Sebranek, and Bregendahl 2008). Surprisingly, the thigh meat of chicken marketed as organic was higher in protein than conventional and free-range chicken, as well as lower in saturated and higher in monounsaturated fatty acids. The diets and production environment of the products purchased, however, could not be confirmed. Thus, it is possible that the chicken in this study marketed as free range may not have had access to pasture, whereas that of the organic chicken did.

FOOD SAFETY

Food safety is another factor in the production system debate. For poultry meat production, *Salmonella* and *Campylobacter* are the main pathogens of concern. The most significant public health risk is transmission of *Salmonella* to humans via eggs. A Finnish study, however, showed that organic laying flocks that have access to the outdoors are commonly colonized by diverse strains of *Campylobacter jejuni* (Sulonen et al. 2007).

Eggs

In European table egg production, three areas of concern have been defined by the Codex Alimentarius Commission (2001). These include microbiological (pathogens), chemical, and physical contamination. The management systems and facilities used to house laying hens can exert powerful influences on the sources, transmission, and persistence of pathogens such as *Salmonella enteritidis* within flocks (Carrique-Mas et al. 2009). Diverse and sometimes contradictory results have emerged from prior research comparing the effects of the various housing systems on the prevalence of *Salmonella* infection and environmental contamination. Poultry with access to outdoor areas are vulnerable to pathogen introduction from external sources, which can be a particularly significant *Salmonella* risk factor (Mollenhorst et al. 2005). In contrast, Van Hoorebeke, Van Immerseel, De Vylder, and colleagues (2010) reported that the housing system had no significant effect on the incidence of *Salmonella* in laying hens. It is important to note, however, that all flocks sampled had been vaccinated against *Salmonella* with an attenuated vaccine. The use of vaccinations, therefore, could eliminate the differences between the two systems as far as *Salmonella* contamination is concerned.

Hens in free-range systems were reported to have a higher ratio of dirty eggs (Yilmaz Dikmen et al. 2016). Cage-free housing systems were reported to be associated with higher levels of *Enterobacteriaceae* bacteria (*Salmonella* is among this family of bacteria) on egg shells (Jones and Anderson 2013), more frequent *Salmonella* isolation from environmental samples, and a greater likelihood of horizontal transmission of *Salmonella* infection within flocks (De Vylder et al. 2011; Hannah et al. 2011; Watanabe et al. 2012). In other studies, cage-based housing systems were associated with a higher probability of *Salmonella* infection in flocks, especially in the presence of large populations of rodents (Huneau-Salaün et al. 2009; Snow et al. 2010; Van Hoorebeke, Van Immerseel, Schulz, et al.

2010). A third group of studies identified no significant differences between cage-based and cage-free flocks in either *Salmonella* fecal shedding or environmental contamination (Jones, Anderson, and Guard 2012; Siemon, Bahnson, and Gebreyes 2007). These conflicting observations appear to be due to the influence of rodents and insects that remain in the facility after cleaning and disinfecting. The high-incident rate reported in some cage systems may be related to the rodent population becoming infected and reinfecting hens by fecal contamination of feed.

Other management factors could have impacts including vaccination, improper cleaning, or sanitation. The elevated levels of contamination come into play when eggs that are not laid in the nest boxes, such as floor eggs or eggs laid on the paddock, are collected, washed, and sold. Mallet and colleagues (2006) showed that eggs laid in the dust bath and other areas of the cage-free system had higher total bacteria and enterococci than eggs laid in the nest. The contamination rates for these floor eggs may be logarithmically higher than eggs laid in the nest, and the times the eggs were exposed to the fecal contamination are not known. De Reu and colleagues (2005) indicated that eggs from hens housed in aviaries had higher total aerobic bacteria than either conventional or enriched cage systems. There was no appreciable difference in aerobic bacteria between the conventional and the enriched cage systems. In later studies (Singh, Cheng, and Silversides 2009), eggs from conventional caged hens were found to have lower levels of *E. coli*. and other coliforms when compared to nest and floor eggs from hens in free-range systems. De Reu and colleagues (2006), however, reported that eggs from alternative systems, including free range, had lower gram-negative bacteria.

Based on these studies, the main factors that put poultry flocks at risk for microbiological contamination include the season of the year (Jones, Anderson, and Musgrove 2011); the size and strain of the flock (Muir and Aggrey 2003), with larger flocks having a higher incidence rate; housing system, such as outdoor access or cage free and management (De Rue et al. 2009); control of rodents and other pests; cleaning and sanitation; and mixing of hen ages. Namata and colleagues (2008) identified additional factors such as the rearing environment, ventilation, or vaccination programs.

The chemical contaminants related to food safety include dioxins, polychlorinated biphenyls, pesticides, and heavy metals (Holt et al. 2011). The dangers associated with these compounds are well documented and represent a significant food safety concern. They tend to accumulate through the food chain and are not readily cleared by the body but stored in fat tissue. Dioxin compounds, which are very stable and persistent in the environment and in animal tissues, have been found associated with eggs from free-range flocks (Chang et al. 1989; Harnly et al. 2000). A study in California conducted near a former paper mill found hens on soil produced eggs with polychlorinated dibenzodioxin (PCDD) and polychlorinated dibenzofuran (PCDF) levels 100 times higher than eggs from conventional cage hens. A study in Europe also found higher PCDD and PCDF levels in eggs from free-range hens (Schoeters and Hoogenboom 2006). These authors observed similar contamination in eggs produced near urban areas as well as from eggs in rural areas where PCDD levels would have been considered low.

Another aspect of PCDD levels in eggs is related to the use and access a flock has to the outdoor range. Kijlstra, Traag, and Hoogenboom (2007) found that the smaller the flock size, the higher the PCDD levels in the eggs they produced, and the larger flocks had lower levels. This appears to be related to the fact that small flocks are out on the paddocks during the daylight and larger flocks have a greater propensity to remain indoors, thereby limiting the PCDD intake.

Pesticides and heavy metals can also contaminate the environment and contaminate eggs from free-range flocks at levels that reflect the soil's contamination. Vieira, Torres, and Malm (2001) reported that dichlorodiphenyltrichloroethane (DDT) levels in eggs produced on free-range farms were 1,000 times greater than the levels in commercially produced eggs. Given the persistence of pesticides and heavy metals in the environment, and that poultry are omnivores, free-range hens will ingest these compounds and accumulate them in both their body fat and eggs (Holt et al. 2011). An unsuspecting source of chemical contamination may be in pressure-treated lumber for fencing and building construction, particularly in older construction. The chemicals used in treating these materials to resist insects and rot could find their way into the paddocks and soils contributing to the chemical contamination of the laying hen or meat birds on those paddocks (Marczew et al. 1989).

As the number of urban egg production flocks continues to grow across the United States, a new food safety concern has arisen—lead. Spliethoff and colleagues (2014) measured lead concentration in eggs from New York City community gardens, and lead was detected between 10 and 167 parts per billion (ppb). In contrast, lead from store-bought eggs were less than 7 to 13 ppb. Rural areas, however, are not immune to lead contamination. Lead has been found in eggs from chicken raised in rural areas of Belgium (Waegeneers, Hoenig, et al. 2009; Waegeneers, Steur, et al. 2009). Lead contamination in eggs was less than 2 to 477 ppb. Lead egg contamination was significantly associated with soil lead levels that were found to range from 12 to 174 parts per million. In a lead-transfer model, the authors concluded that soil lead levels accounted for up to 92% of the lead in the eggs (Waegeneers, Steur, et al. 2009).

Another point of concern that has received almost no attention is the use of compounds treating free-range poultry for external and internal parasites. These antiparasitic compounds could be either absorbed or ingested, pass through the hen's system, and end up in the production environment. Eggs from the commercial operations using these appear to have higher concentrations due to the increased use of these chemicals to control the insect populations (Hamscher et al. 2003). Intestinal worms are becoming a greater issue as poultry move from cages to litter floors to outdoor paddocks. To control these organisms, a variety of compounds is used (Ssenyonga 1982; Young and Dawe 2008), most of which require withdrawal periods but, nonetheless, would be recycled in the cage-free or free-range environment.

In 2017, eggs tainted with Fipronil were discovered in eggs produced in Belgium and the Netherlands and found in several European countries. Fipronil is commonly used by veterinarians to treat fleas and ticks on cats and dogs. It is not allowed for any animal entering the food chain. Around 180 Dutch farms were temporarily shut down, and a criminal investigation was launched. Two men were arrested for the illegal use of Fipronil at poultry farms to treat red mites, which can be a problem in cage-free egg production systems.

Meat

Many consumers believe that free-range organic poultry meat is safer than that of conventional poultry. This is not necessarily true, because Näther and colleagues (2009) reported that the prevalence of *Campylobacter* was significantly higher in flocks from free-range and organic farms in Germany when compared to conventionally raised broilers. This was confirmed by several researchers in other areas of Europe (Bokkers and de Boer 2009; Esteban et al. 2008) and the United States (Van Loo, Alali, and Ricke 2012). Outdoor production systems result in longer rearing times because of either the breed or the environment, thereby increasing the risk of contamination. With outdoor access, broilers and turkeys will be more prone to exposure to stress from environmental conditions, wild birds, and animals, as well as insects and rodents (Lubin, Samish, and Mishoutchenko 2003; Lund 2006). Van Loo, Alali, and Ricke (2012) cautioned that comparing the results between studies is difficult because of differences in geographic locations, seasons, and detection and isolation methods.

The source of *Campylobacter jejuni* contamination in poultry flocks has yet to be definitively determined. A yearlong study by Colles, Jones, and colleagues (2008) examined *Campylobacter jejuni* shedding in flocks of free-range chickens as well as wild birds in the area. Although both populations were shown to shed *C. jejuni*, there was a high degree of genetic difference between the chickens and wild birds, suggesting that the wild birds were not the source of the *C. jejuni* contamination. This was confirmed by Colles, Dingle, and colleagues (2008), who examined wild geese and found that they carry *Campylobacter*, but there was limited mixing of *Campylobacter* populations among geese, starlings, and free-range chicken populations. They concluded that geese are not likely to be sources of human cases of *C. jejuni*.

Interestingly, Young and colleagues (2009) indicated that although organic broiler chickens had higher levels of *Campylobacter* at slaughter, there were no differences between organic and conventional in the prevalence of *Campylobacter* at the retail level. Bacteria isolated from conventional poultry had a higher incidence of resistance to antimicrobials, but some of the resistant strains were also identified in a number of organic production systems as well.

Regardless of the research conclusions concerning relative food safety of chickens from different systems, consumers should not assume that all free-range or organic chicken are free of *Salmonella* and *Campylobacter*. Bailey and Cosby (2005) surveyed the microbiological status of chicken from different lots from four different free-range chicken producers and reported that 64% of the lots and 31% of the carcasses were positive for *Salmonella*. For the “all-natural” chickens sampled, 37% of the lots and 25% of the chickens tested positive. The sampled lots from organic chicken all tested positive for *Salmonella*, with 60% of the individual carcasses testing positive. Alali and colleagues (2010), however, showed that within a North Carolina poultry company, the prevalence of fecal *Salmonella* contamination was lower in certified organic chickens and the prevalence of antimicrobial-resistant *Salmonella* was higher in conventionally raised chickens than in those certified organic. A major source of contamination in the conventional chickens may have been the feed. Contamination of feed samples from organic and conventional farms were 5.0% and 38.8%, respectively.

POULTRY HEALTH

Flock Health

Optimal health management is key to successful poultry production. Studies have shown increased mortality in free-range production systems compared to conventional cages (Eigaard et al. 2003; Sossidou et al. 2011; Wongrak et al. 2014). Diseases are caused by bacterial, viral, and parasitic agents. Diseases, at the worst, kill, or, at the least, rob a flock of optimal productivity. Many infections that do not kill the host rob it of vitality by impaired appetite, decreasing efficiency of nutrient absorption, or disrupting the function of other essential systems such as the respiratory tract or excretory and immune systems.

It is unclear how the housing situation affects the immune system of poultry. Antibody production has been shown to be significantly higher in caged hens (Arbona, Anderson, and Hoffman 2011). Caged hens also had the greatest ratio of heterophil to lymphocytes, which is an indication of stress. Comparing immune response of laying hens kept in battery cages, on the floor with litter and perches, or in a free-range housing environment, research has shown that the antibody response is higher in battery cages and on-the-floor housing (van Loon et al. 2004). In addition, the titers remained higher in battery cages. The *T-cell* response, however, was higher in free-ranging hens. In contrast, Rehman and colleagues (2017) reported that vaccinated hens in semi-intensive and free-range egg production systems had higher antibody titer against Newcastle disease (ND) and infectious bronchitis viruses.

There are several reports indicating that the incidence of helminth infections (*Ascaridia galli*, *Heterakis gallinarum*, and *Capillaria* spp.) is higher when poultry have outdoor access as compared to the incidence of such infections when raised in conventional housing (Permin et al. 1999). Kaufmann and colleagues (2011) evaluated the intestinal parasite load of hens raised on organic free-range farms where outdoor access is required. They reported that 99.6% of hens examined had nematode or cestode infestation. The probable reason for this is, with outside access, poultry will ingest insects and other invertebrates, such as earthworms, that serve as intermediate hosts for several digestive tract parasites. In low numbers, roundworms (*Ascaridia* sp.) appear to have little deleterious effect on the vitality of the host, but they can increase carcass condemnation or decrease egg production.

Insects, such as flies and darkling beetles, serve as intermediate hosts for tapeworms that complete part of their life cycle in the insect. In caged chicken egg layers, tapeworms can occur if flies are numerous. Flies can become infected in one location and fly to another. The flies are then able to get into the feeders and be consumed by the chickens. In free-range systems, poultry are expected to forage and ingest insects that potentially harbor an intermediate form of the tapeworm. Once the insect intermediate host is ingested, the tapeworm is released and matures in the intestine of the poultry host and begins producing eggs. In low numbers, the tapeworm appears to have a minor deleterious effect on the vitality of the host or on the production of eggs. In heavy infestations, they may occasionally migrate out of the digestive tract through the cloaca and into the oviduct where they may become incorporated into an egg. This is extremely undesirable for the consumer. The incidence of tapeworms in free-range poultry can be high (Kaufmann et al. 2011). The cecal worm (*Heterakis gallinae*), which is a nematode parasite carried by the earthworm (transport host), carries the protozoal parasite *Histomonas meleagridis*, the cause of blackhead disease (histomoniasis), which can be deadly to turkeys. Blackhead is now becoming a problem in cage-free, free-range, and organic flocks of laying hens. Broiler breeder flocks are susceptible to blackhead as well.

Rotational grazing of the paddock area was not found to have an effect on the worm burden (*Ascaridia galli*, *Heterakis gallinarum*, *Capillaria* spp.) of free-range laying hens (Maurer et al. 2013). There is some research, however, that shows that there may be genetic differences in the susceptibility to *Ascaridia galli* infections (Permin and Ranvig 2001), which may provide a tool for geneticists when selecting breeders for free-range poultry production in the future.

The type of soil media in the free-range system can affect the level of nematodes present (Sossidou et al. 2008). Composting recycled vegetable waste has been shown to decrease nematodes per gram of dry soil. In Europe, the EU Waste Management Strategy has resulted in increased low-cost composted recycled vegetable waste. Composting eradicates nematodes from the vegetable material and lessens the ability of nematodes, and some bacteria, to repopulate the material. Such composted material can act as a good soil medium, and good forage material can be established.

Coccidiosis is caused by infection with a single-celled protozoal parasite in the genus *Eimeria*. The organisms are host specific. Every class of poultry and livestock has at least one species that affects them. It is common in animals raised on solid surfaces, whether on dirt or concrete. Every commercial livestock enterprise has some type of control program for this parasite. Coccidiosis is most devastating in young animals, but it can occur in older animals that have not been previously exposed. Chickens, in particular, are susceptible to coccidiosis at any age. Lampkin (1997) identified coccidiosis as the major health issue with organic chicken meat production as well as pullet rearing. The problem was found to be less serious for layers because adult chickens can rely more on natural immunity. Fisker (1998), however, indicated that there is little evidence to suggest that coccidiosis is a major problem in organic chicken meat production in Denmark, despite the ban on the prophylactic use of anticoccidials.

Fowl cholera is caused by infection with *Pasteurella multocida*, which may be present in most species of wild birds. Transmission of *Pasteurella multocida* from wild birds to domestic poultry has been demonstrated (Sossidou et al. 2011). It is associated with high death losses in poultry, especially turkeys. It can be easily carried on *fomites* and spreads through water. The disease is prevented by strict biosecurity methods, and live and killed vaccines are available. The vaccines do not completely prevent infection, but they greatly lessen the severity of the disease. Comparing the genetic makeup of fowl cholera strains isolated from Danish free-ranging flocks and those of isolated waterfowl showed that they were closely related (Christensen, Dietz, and Bisgaard 1998). A longitudinal investigation on the causes of mortality carried out at a Danish farm with organic layers demonstrated establishment and spread of fowl cholera and that losses in free-range chickens can reach as high as 91% (Stokholm et al. 2010). Although not all studies demonstrate fowl cholera problems in free-range poultry (Fossum et al. 2009), the findings of Stokholm and colleagues (2010) demonstrate the potential. A negative interaction between roundworms and the bacterium that causes fowl cholera has been reported, leading the authors to suggest that free-range chickens are at a higher risk of being subjected to outbreaks of fowl cholera when they are infected with roundworms.

Disease Spread

There is concern that free-range poultry may serve as reservoirs of disease exposure to conventional production systems. Avian influenza and exotic Newcastle disease (END) are the two most serious diseases of concern. This is not only because of the high mortality they cause, but also because of the economic impact that may result due to trading restrictions and embargoes placed on infected areas. Many countries, including the United States, enforce strict control measures in the event of outbreaks of either of these two diseases.

Concerns are based on the contact with wild birds and other animals common in free-range poultry. Free-range flocks are at a similar or higher level of risk as the conventionally reared flocks because of the lack of solid barriers to reliably keep out wild birds and mammals. Even though intensive rearing provides much more control of exposure opportunities, having a source of infection in the neighborhood with free-range flocks increases the potential of an infectious agent entering a closed house by some means. As a result of minimal clinical signs while shedding the virus in the early stages of the infection, it is theoretically possible that infected free-range flocks could be a source of infection and contamination for other poultry in the area.

There are several categories of infectious agents, and the possibilities of transmission from a reservoir vary considerably among them. The role of passerine and terrestrial wild birds in the spread of AI may be minimal (Forrest, Kim, and Webster 2010), however, given that there is no evidence to indicate that they are a natural reservoir of the virus (Slusher et al. 2014). To properly understand the risks associated with wild birds, a better knowledge of the interaction between wild birds and poultry is needed, as well as of the possible transmission of influenza virus between these two populations. Passerine birds could enter the barns and infect poultry directly or contaminate surfaces near poultry barns. This contamination can be transported by farm workers, equipment, rodents, and insect pests to the poultry (Burns et al. 2012).

Burns and colleagues (2012) documented wild bird activity on poultry farms in two major poultry-producing regions of Canada. Of the nearly 300 wild birds known to inhabit these areas, approximately 20% were observed in the vicinity of commercial poultry farms. These included the American robin, barn swallow, common grackle, dark-eyed junco, European starling, horned lark, northwestern crow, rock dove, and song sparrow. There is very little information published on the presence of the AI virus in these species. Burns and colleagues (2012) also identified conditions that resulted in large flocks of birds near poultry farms. These included flooded pastures and harvested corn fields. Freemark and Kirk (2001) reported that the practices of noncrop habitat, more permanent crop cover, and less intensive management on organically managed cropland lead to increased diversity of bird populations. This may be critical to maintain avian diversity, but for those mixed-farming operations, it brings more birds in closer proximity to the poultry houses.

In 2014 there was an outbreak of AI in British Columbia, Canada. In 2015, it spread to California and then the Midwest. According to an epidemiological analysis, the incidences occurred on the Pacific and Mississippi flyways, and migratory fowl are believed to have played a role in the outbreak (USDA–APHIS–VS 2015). It should be noted, however, that no free-range commercial poultry flocks were reported to be infected in the 2015 outbreak. This may be due to the Midwest outbreak occurring during the winter when those birds would have been confined indoors because of the cold outside temperatures and thus be less vulnerable to exposure. It is important to note that many of the hobby-type producers are less likely to seek a diagnosis if they have dead birds because their financial livelihood was not dependent on the flock and they do not always have affordable access to an avian veterinarian or diagnostic lab. It is interesting to note, however, that the first introduction of the virus into egg-producing chickens occurred in a backyard flock.

The AI outbreak in British Columbia occurred in the winter months when waterfowl are at their highest numbers near poultry farms. Free-ranging flocks in close proximity to water reservoirs, therefore, would be more likely to have interaction between wild waterfowl and the poultry flock. The Swiss national monitoring of AI in wild waterfowl and free-range poultry farms documented the introduction of AI in Switzerland by wild waterfowl in mid-February 2006. As per the surveillance reports, however, the virus was not detected in the free-range poultry flocks at the same time period (Dalessi, Hoop, and Engels 2007).

Based on surveillance data, there is a significantly higher risk of introducing AI on farms with *Anseriformes* species (duck, geese, and game birds) compared to those housing *Galliformes* poultry types (broilers, layer chickens, and turkeys) (Gonzales 2012). Outdoor chicken egg production as well as duck (breeders and meat) and turkey farms were shown to have a significantly higher risk of introduction of AI compared with indoor egg production farms. This may be due to their higher risk of exposure to an AI-contaminated environment and/or contact with wild waterfowl. Their longer production cycle would also affect the length of exposure. In a study in the Netherlands, outdoor layer, turkey, duck-breeder, and meat-duck farms had an 11, 8, 24, and 13 times higher rate of introduction of AI than indoor layer farms, respectively (Gonzales et al. 2012).

The 2003 AI outbreak in the Netherlands resulted in 87 human cases. There is a continuing threat of a new influenza pandemic developing from avian influenza (Kuiken et al. 2003). Chicken to human transmission of avian influenza has been reported in Asia and the Netherlands. To date, human to human transmission has been very limited.

There are three forms of the ND: lentogenic (mild), mesogenic (medium clinical signs), and velogenic (severe disease, also known as END). Both live and killed vaccines for commercially reared chicken and turkeys are available. Flocks infected with the velogenic strains (END) are eradicated when detected. Wild birds can transmit the disease to free-range flocks. In 1992, for example, it was documented that cormorants in North Dakota transmitted ND virus to a free-ranging turkey flock (Heckert et al. 1996). In addition, END was confirmed in a backyard flock in the state of California in October 2002. Within six months, the disease had spread to backyard flocks in Nevada, Arizona, and Texas. In California, the virus was eventually transmitted to commercial poultry. As a result, 3.5 million birds were destroyed to eradicate the disease. In May 2018, END was again detected in backyard flocks in California. All the initial flocks were exhibition chickens. It is not yet clear how the flocks were infected and how the disease spread.

Mycoplasma is another disease-causing organism of concern in commercial poultry flocks, especially those with outdoor access. The National Poultry Improvement Plan (NPIP) has a control program for testing and elimination of breeder flocks infected with *Mycoplasma gallisepticum* (MG). Many of the commercial egg production flocks, however, are infected. Flock infections cost producers in condemnation at slaughter of meat birds and in loss of egg production in egg-producing flocks (up to 12 eggs lost per hen out of the 250 eggs expected by 60 weeks of age [Mohammed, Carpenter, and Yamamoto 1987]). There are live and killed vaccines available to help control or mitigate the effects of MG infections. Vaccines, however, do not eliminate the infection. Chickens, especially the white leghorn, are more resistant to the effects of infection than turkeys and can serve as a source of infection for them. There have been anecdotal reports of outbreaks in turkey flocks associated with hauling spent laying hens past a turkey farm (Mohammed, Carpenter, and Yamamoto 1987). The organism, therefore, can be spread from one farm to another. Many backyard flocks have birds that are not sourced from NPIP-certified flocks, and outbreaks of MG have been reported.

Infectious laryngotracheitis (ILT) is a disease that primarily affects chickens, but it can also infect pheasants and peafowl. Chickens must be in fairly close contact for transmission among them. The virus, however, can survive for short periods of time to be transported on fomites and clothing if conditions are cool and moist. If a chicken survives the infection, it is a carrier for life and can shed the virus at irregular intervals. An infection of ILT is more readily spread from acutely infected birds than from contact with latently infected birds (Swayne et al. 2013). The likelihood of airborne spread is not well documented. The virus can be carried short distances, however, on a variety of fomites that have been contaminated by contact with materials from infected birds (Swayne et al. 2013). It frequently appears in backyard chickens after exposure at various expositions when they contact sick or latently infected birds.

It is not common for nematodes to be present in caged laying hens. Confined poultry on solid flooring, especially if the litter is reused, often have roundworms. It is unlikely that free-range poultry would serve as a reservoir and source of infestation for confined poultry because of the separation of the caged birds from their fecal material. Some nematodes are carried by invertebrates. Their presence in confinement poultry would indicate a breach in biosecurity in the area of pest control rather than some means of exposure to an infested free-range flock. With regard to cestodes, insect intermediate hosts may be readily available to both free-range and confined poultry. Infested free-range flocks would not be considered a reservoir for conventionally reared commercial poultry.

ENVIRONMENTAL IMPACT

The main aim of sustainable animal production is to produce a high-value animal protein in a sustainable manner. Sustainability, however, is hard to define. Producers are under intensive pressure to minimize the impact of their production on the environment or carbon footprint. Putnam and colleagues (2017) completed a retrospective analysis of the U.S. poultry industry from 1965 to 2010. They found that climate change, acidification, and eutrophication impacts associated with chicken meat production decreased by 36%, 29%, and 25% per 1,000 kg (2,204.62 lb) of meat produced, respectively. There were also reductions in resources required. Fossil energy use decreased by 39%, water depletion by 58%, and agricultural land occupation by 72% per 1,000 kg (2,204.62 lb) of chicken meat produced.

The environmental impact of poultry production depends on several factors, and waste disposal is a primary concern. If properly managed, the manure and litter produced is a valuable resource. The large amount of waste generated, however, may exceed the local demand, making poultry waste a potential problem instead of a valuable resource. It is possible to turn manure from a cost and negative environmental impact to a money-making enterprise. This requires proper handling of the manure and development of a distribution plan that does not overload a specific area.

There has been very little research looking at manure deposition in free-range poultry facilities. Larsen and colleagues (2017) used RFID to look at range use on two commercial free-range egg laying farms in Australia. They identified three areas of the range based on the distance from the shelter. They included the veranda (0–2.4 m [0–2.62 yards]), close range (2.4–11.4 m [2.62–12.47 yards]), and far range (>11.4 m [12.47 yards]). They found that most hens used the range every day (68.6% for one flock and 82.2% for the second). Hens typically only spent 14% of their time on range (Larsen et al. 2017), which would imply that most of the manure would be deposited in the poultry house. The hens spent half their outdoor time in the veranda area adjacent to the shelter. This would be the area of heaviest manure build up, possibly leading to nutrient runoff. Wiedemann and colleagues (2018) showed that soil nitrate and colwell-phosphorus (available for plant update) in free-range egg layer operations in Australia were concentrated within 6 m (6.56 yards) of the poultry house.

Lee, Wen, and Chang (2010) reported that nutrient loading in free-range poultry operations in Taiwan can lead to environmental problems from leaching and runoff. Similar findings were reported by Kratz, Rogasik, and Schnug (2004) for chicken meat production and by Haneklaus, Schnug, and Berk (2000) for turkey meat production, both in Germany. Jones and colleagues (2007), however, did not detect changes in groundwater nitrate and phosphate concentrations associated with the expansion of free-range poultry production in the UK. The relative environmental risks from excessive nutrient loading of range area will be site specific and will depend on a number of environmental factors, especially soil type.

Some free-range systems use bottomless, moveable shelters in which the manure is deposited directly to the range and the shelters moved regularly. Although these represent a small proportion of the commercial flocks, they do provide a means to evenly distribute the manure in the range area, minimizing nutrient buildup.

Animals, feed, manure, and housing accessories contribute to potential sources of the environmental footprint. The impact of poultry production on the ecological systems may result from direct release of airborne constituents into the atmosphere, direct runoff to water bodies, leaching to groundwater, or indirect deposition of airborne constituents into water bodies. The different commercial poultry production facilities vary significantly in terms of housing and manure handling practices. Different housing options vary in the ability to regulate environmental conditions that will, in turn, affect resource utilization efficiency. There is very little research comparing the efficiency of free-range production to more confined systems. Livestock production is believed to have a major impact on the environment, and consumers are looking to include more environmentally friendly products in their diet. Comparative assessments of free-range and conventional production systems, however, can be difficult. There are often differences in strains used and feed formulations, in addition to the differences in production systems. Bokkers and de Boer (2009) compared conventional chicken meat production raising a fast-growing strain with organic chicken meat production raising a slow-growing strain, both on the same farm in the Netherlands, and reported that the organic system with outdoor access had higher emissions of greenhouse gases (GHGs), higher use of fossil fuels, and increased land use.

Not all forms of energy have the same "quality." Solar emergy measures solar (equivalent) energy. Emergy evaluation is a tool for evaluating environmental impact of animal production systems. It is expressed as solar emjoules. Castellini and colleagues (2006) used this approach to compare conventional and organic chicken meat production for the period covering cradle to gate. The conventional system with a fast-growing strain of chickens reared in a well-controlled environment and using veterinary treatments (coccidiostats and antibiotics) outperformed the slower-growing strain of chickens in the organic system with outdoor access. In both systems the poultry feed represented 50% of the emergy flow. Although the performance was lower for the organic system, the environmental impacts were also lower.

There are different methods for assessing the environmental impact of poultry production systems. One is GHGs. Greenhouse gas emissions, however, are only part of the environmental impact. Ammonia and particle emissions are also released from poultry houses. In addition, energy is used directly for feeding, heating, lighting, and ventilation. The life cycle assessment (LCA) method considers the environmental burdens and resource use over a specific period of the production cycle. Leinonen and colleagues (2012a) used the LCA method from cradle to farm gate to compare the environmental burden of egg production in four production systems in the UK: conventional cage systems, barn systems (cage free), free range, and organic. The number of hens needed to produce 1,000 kg (2,204.62 lb) of eggs was highest for the organic production system, which also had the highest amount of feed consumed per hen. It was largely these general differences that affected the environmental impacts of the systems. The different systems also used different diets, resulting in different environmental burdens per unit of feed. Overall, the results showed that the cage system had the lowest eutrophication and acidification potentials, as well as lowest primary energy use and global warming potential (GWP). Comparing the cage and free-range systems, the hens in cages produced more eggs, consumed less feed, had lower mortality, less land use, and decreased feed spillage.

Leinonen and colleagues (2012b) also used the LCA method, from cradle to farm gate, to compare the environmental burden of conventional indoor, free-range, and organic chicken meat production in the UK. Different strains were used in each system, with the organic system having a slower-growing strain. They also had different feed formulations. Surprising, the authors reported that the number of chickens required to produce 1,000 kg (2,204.62 lb) of edible carcass was highest for the conventional indoor system. This, however, was due to a lower finishing weight in the indoor system. Mortality, however, was higher and the length of the grow-out period longer in the free-range and organic systems. As a result, feed consumption per chicken was higher in these two systems. The GWP was highest for the type of feed used in the conventional indoor system, primarily resulting from the use of imported soybean meal and palm oil. Comparing the conventional indoor and free-range systems, the conventional system had higher primary energy use, slightly higher GWP, higher eutrophication potential, higher acidification potential, but similar pesticide and land use. Organic systems, however, had the highest primary energy use, eutrophication potential, and land use.

Castellini and colleagues (2012) used a multicriteria approach to compare the sustainability of conventional indoor, organic, and organic-plus (required a slow-growing strain and increased outdoor access) chicken meat production systems in Italy. They looked at economic, social, environmental, and quality factors. Similar strains were used in the conventional indoor and the organic systems; however, the organic-plus system used a different slower-growing strain. The total cost of feed per production unit was 20% higher for the organic system compared to the conventional system. The final weight, feed conversion, and mortality rates were better for the conventional indoor system, but the conventional system was found to have the highest impact on climate change and environmental loading.

The results of Castellini and colleagues (2012) was similar to the results reported by Boggia, Paolotti, and Castellini (2010). They also used the LCA method to compare conventional indoor, organic, and organic-plus chicken meat production systems in Italy, cradle to farm gate. The systems differed in final market weight, strain used, grow-out time, and feed composition, making direct comparison of indoor and free-range production systems difficult. In their study, feed for the conventional system accounted for 78.8% of the overall environmental impact for the conventional indoor system. The main contribution was from the soybeans and corn. Feed production in the organic system represented 87.3% of the total environmental impact, whereas it was 87.8% in the organic-plus system. The organic-plus system had the highest land use. The overall results of the study showed that the organic system had a better environmental performance than the other two systems.

As indicated previously, mortality rates tend to be higher in free-range production systems compared to conventional indoor systems (Eigaard et al. 2003; Sossidou et al. 2011; and Wongrak et al. 2014). Weeks, Lambton, and Williams (2016) completed a mega-analysis of ten studies in the UK and reported that, whereas cumulative mortality for free-range layer flocks averaged 7.89%, it ranged from 0 to 69.3%. High levels of mortality decreased the sustainability of egg production. They investigated how changes in cumulative mortality affect the environmental burden of flocks. The general effect of increased cumulative mortality was to increase all environmental impacts, including GHG emissions, eutrophication potential, acidification potential, pesticide use, abiotic resource, and land occupation. If the higher mortality could be decreased to levels associated with caged production, GHG emissions could be lessened by 25%. The results show the potential scale for the effect of very poor management, housing, or biosecurity.

On a global scale, livestock occupy about 70% of all the agricultural land and 26% of the ice-free land surface (Steinfeld et al. 2006). With the still-growing global population and per capita incomes, the amount of food required will be considerably higher in years to come. To meet this demand, we will need to have better feed efficiency in animal food production, decreased food wastage, and dietary changes in favor of vegetable food and less-demanding meat (Wirsenius, Azar, and Berndes 2010). The switch to free-range poultry production systems is counter to this with decreased production performance, decreased feed efficiency, and increased land use (Golden, Arbona, and Anderson 2012).

As previously indicated, the environmental impacts associated with chicken meat production arise primarily from feed consumption. Diet formulation and feed ingredient choice should be considered to mitigate these impacts. Tallentire, Mackenzie, and Kyriazakis (2017) looked at different diet formulations for production systems in the UK and the United States and found that using a multicriteria approach to diet formulation, where environmental impact as well as economic impacts are considered, will be the basis for improving the sustainability of chicken meat production. The two regions were considered separately since legislation, trade agreements, and climatic conditions result in different feed ingredients being used in the two areas. The GWP for the UK system is much higher than that of the U.S. system. This is primarily due to the importation of the soybean meal from South America where deforestation is common. In the United States, however, 100% of the soybeans used in conventional poultry production are grown domestically. In both regions it was not possible to minimize the effect on one category without impacting at least one other. Formulating for decreased environmental impact, for example, results in higher feed costs.

When compared with caged hens, hens kept in floor pens were reported to have decreased egg production rates (Karcher et al. 2015). Moving from intensive (cage) to extensive production systems requires significant increases in labor time commitments—a 45% increase in man-hours from cage to cage free, a 279% increase in man-hours from cage to free range, and a 161% increase in man-hours from cage free to range (Anderson 2014). There are no peer-reviewed studies looking at the man-hours for moveable pens, but presumably they will be the highest. It will vary depending on the size and type of moveable pens used. Based on labor inputs, free-range production is less efficient than caged systems.

CONCLUSIONS

Management is key to optimizing animal welfare in any production system. Although many perceive free-range poultry production systems to be more animal welfare friendly, the research comparing the different production systems is inconclusive and often contradictory. Providing an outdoor run can lead to higher space allowances, an increase in the number and types of behavioral and physiological stimulations, and the freedom to move between different environments with changes in climatic conditions and bird preferences. Based on these criteria, one can assume that there is an increase in animal welfare. It is important to note, however, that there are also increased risk factors that can adversely affect bird welfare. These include increased contact with infectious agents, greater difficulties maintaining hygienic standards, increased possibilities of unbalanced diets, and increased threat of predation.

The main conclusion that can be made with regard to the nutritional composition of poultry products is that it is more reflective of what the bird eats rather than the type of production system used. Outdoor access itself does not alter the nutritional content of the products. It does appear, however, that the nutrient content of poultry meat and eggs can be enhanced with access to pastures, with the effect depending on the type and quality of the pasture provided.

Food safety is an important consideration with any production system. For poultry meat, *Salmonella* and *Campylobacter* are the main pathogens of concern, whereas the most significant public health risk for eggs is the transmission of *Salmonella*, specifically *Salmonella enteritidis*. The research on the bacterial loads of poultry meat from conventional and free-range systems has been conflicting. Comparing results between systems is difficult because of differences in geographic location, seasons, and detection and isolation methods.

Regardless of the research conclusions regarding the relative food safety of chickens, consumers should not assume that all free-range chickens are free of *Salmonella* and/or *Campylobacter*. The same can be said for conventional production systems. Proper handling of poultry meat from any production system is essential and should not be overlooked based on the production system used. The microbial load on eggshells in both cage and free-range nests is comparable from well-managed facilities. The difference comes from eggs that are laid outside of the nest on the floor and the range paddock, which both have microbial populations that even washing cannot decrease to a safe level. The food safety of eggs from the range must also include chemical safety because dioxins, pesticides, and lead can be issues with free-range production in some locations.

There is very little documented research with regard to the disease risks associated with free-range as compared with conventional poultry production systems. It is documented that free-range poultry have more exposure to certain external and internal parasites because of access to invertebrates and wild birds. Although free-range poultry may be more vulnerable to certain diseases, there is no indication that the presence of free-range poultry poses a risk to conventional poultry.

The research results regarding the environmental impact of different production systems vary considerably and are often conflicting. The main issues affecting environmental impact are manure management and feed formulation. Free-range poultry production requires more land at a time when there is high demand for agricultural land.

There is considerable variation in

farming systems used in free-range poultry production. This includes differences in farm size, housing and range availability, and opportunities for pasture rotation. Such differences make it impossible to make general statements with regard to the effect of free-range poultry production on the parameters observed.

GLOSSARY

Cage free. A housing system in which poultry are not maintained in cages.

Fomite. An inanimate object capable of carrying the infecting organism of a disease.

Free range. A system in which poultry have outdoor access, but a shelter or secured outdoor space may or may not be provided.

Free roaming. A housing system in which poultry are not maintained in cages.

Heterophil. The predominate granulated leukocyte in the acute inflammatory response in gallinaceous birds.

Lymphocyte. A type of white blood cell that is part of the immune system.

Minimal processing. Processed in a manner that does not fundamentally alter the product.

Natural. A product containing no artificial ingredients or added colors and that is only minimally processed. Minimally processed means that the product was processed in a manner that does not fundamentally alter the product.

Outdoor access. Production systems that allow flocks to leave a stationary housing structure.

Pasture. Grasses, legumes, brassicas, or other suitable forages.

T-cell. A lymphocyte that actively participates in the immune response.

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