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Pests in Poultry, Poultry Product-Borne Infection and Future Precautions

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Summary

Consumption of poultry and poultry products is growing rapidly in both developing and developed countries as a result of increasing demand for foods rich in proteins, a world population of over 7 billion, and increased concern about the role of red meat in health and nutrition. This has led to an integration of the poultry industry to achieve enhanced productivity through economies of scale. However, simple mistakes in management in a huge integrated commercial poultry production can have substantial adverse impacts due to a number of pests such as arthropods and rodents associated with foodborne infections. A large number of microorganisms that cause infection in humans or both human and poultry flocks are transmitted to poultry by these pests. However, concerns about pesticide residues are discouraging the use of these agents in poultry industries, thus increasing the reliance on bio-security practices to control infestations. Free range and pasture-flock poultry are popular, but the pasture-flock poultry and poultry products pose potentially higher microbial risks to a large population due to longer production cycle and easy access for pests and other animals. In this chapter, we focus on poultry pests involved in the transmission of microbial pathogens to poultry flocks which result in an increased risk of foodborne infections in humans, loss of food quality, and greater risks for poultry industries.

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26.1 Introduction

Food safety can be defined as the system of controls that keeps food and food products free from substances that are hazardous to human health. In this definition, a 'hazard' refers to any physical, chemical, or biological agent or condition that may cause an unacceptable risk to human health (FAO, 1998).

Poultry is a huge industry and poultry animals and corresponding products could be touched and contaminated with foodborne pathogens by soil, water, and also materials within the other poultry products' gut. In the poultry industry, the presence of pathogenic microbes in poultry product is an unavoidable fact of life in both developed and developing countries. Pathogen contamination of poultry is widely known; they infect millions of people every year, resulting in billions of dollars loss due to related health care and production lost. In the United States, the two most prevalent pathogenic bacteria associated with poultry products are *Salmonella* and *Campylobacter* (Bailey, 1993; Wilke *et al.*, 2011). However, within the intestinal lining of poultry such as chicken, many different *Salmonella* and *Campylobacter* serotypes live benignly. Because these pathogens are very resilient, they persist into slaughter and production plants.

For commercial poultry businesses worldwide, pests are a major concern both from the viewpoint of productivity and potential safety concerns. It is well recognized that pests are frequently associated with infrastructural damage (facility damage) or the feeding of contaminated feed and feed ingredients (e.g. mycotoxin-contaminated grains) (Kaufman *et al.*, 2002). Wild pests can be reservoirs and vectors of many agents that cause diseases in food, animals, and human beings (e.g. *Leptospira* spp., *Salmonella* spp., *Campylobacter* spp., *Trichinella* spp., *Toxoplasma* spp.; Hiett *et al.* 2002; Meerburg and Kijlstra, 2007). For instance, high-density confined housing systems widely used in large commercial poultry production operations create environments that favor the survival and development of flies, beetles, and northern fowl mites as a result of manure and poultry litter accumulations. It has been well documented that flies play an important role in transmitting enteric pathogens such as *Salmonella*, enterohemorrhagic *Escherichia coli*, and *Listeria monocytogenes*. Beetles associated with poultry litter and accumulated manure could result in structural damage to poultry housing, serve as reservoirs for potential illness, and create community problems during clean-out of the house (Tomberlin and Drees, 2007). Large populations of northern fowl mite can result in direct economic losses by influencing bird health and production (Meerburg and Kijlstra, 2007; Mullens *et al.*, 2010). Additionally, potential biological control agents such as predaceous mites, parasitoids, and hister beetles that can suppress fly populations are also associated with poultry manure (Rutz and Pitts, 2000).

There are two general strategies for reducing consumers exposure to foodborne pathogens: (1) prevention to stop food hazards from entering the food chain, and (2) intervention to eliminate or reduce pathogens that have entered the food chain to an acceptable level. In current poultry farming practices, a top priority is the development and implementation of effective control measures that reduce zoonotic pathogens, particularly *Salmonella* and *Campylobacter*.

There are many prevalent vectors on poultry farms for both *Salmonella* and *Campylobacter*; however, it is almost impossible to eliminate them from the poultry gut. Fortunately there are many practical measures that can effectively reduce the exposure of these vectors to broiler flocks (Vandeplas *et al.*, 2008; Neal-McKinney *et al.*, 2012). Although people have developed many useful technologies to control these pathogens, due to the complexity of poultry source and point contamination current programs or strategies have not been fully successful in controlling these pathogens. In the past, pest control measures almost totally relied on pesticides for maintaining pest populations below economic injury thresholds or nuisance levels. Since these thresholds were not well defined, control practices were generally not performed until after the pests were found on the poultry or in the poultry house (Blancou *et al.*, 2005).

Small losses due to pests or animal diseases can have significant economic impacts for the farmer and related poultry industries, particularly for large-scale poultry production operations. It is generally agreed that the most effective way to manage these risks is through an integrated pest management approach that is consistent with the current poultry production systems and related management strategies. The objective of this chapter is to describe and discuss important poultry pests, the role of these pests in transmitting microbial pathogens to poultry flocks, and the principles for their management in modern, large-scale commercial poultry production systems.

26.2 The potential risk of contamination in poultry

26.2.1 Conventional poultry

In conventional poultry industry, there are three types of foodborne risk factors affecting the health of humans (Serra *et al.*, 1999; Lupo *et al.*, 2010): (1) microbiological factors such as *Campylobacter* spp., *L. monocytogenes*, and *Salmonella* spp.; (2) chemical factors such as residues from disease-treating medications, feed additives, pesticides, or environmental pollutions; and (3) physical factors such as bone-pieces in meat or iron nails entering from processing.

From a public health viewpoint, the most important group is the first which includes pathogenic microorganisms such as *Salmonella*, *Campylobacter*, *L. monocytogenes*, *Clostridium perfringens*, and pathogenic *Escherichia coli*. Recent concerns about the potential for viruses to change its host ranges is an emerging issue (e.g. avian influenza). On the other hand, helminthes, prions, and protozoa are generally not major sources for zoonotic diseases that are transmitted via poultry products. Microbiological risk factors are so prevailing that they can be found in almost all systems of poultry production. In shell eggs for instance, the most common foodborne microbial pathogens are *Salmonella* spp., *Campylobacter*, *Listeria*, and other enterobacteriaceae. Shell eggs can be infected via transovarial transmission prior to laying or due to contamination from the environment. Physical damage such as cracks of the egg shell can greatly increase the risk of contamination (Humphrey, 1994; Forshell and Wierup, 2006).

Salmonella enterica is one of the most common pathogens associated with poultry. It is easily transmitted during handling and processing of poultry products, especially non-processed and non-heat-treated products. As poultry producers increase the size of their operations to take advantage of the economies of scale, the number of birds that can be affected by a transmission event increases significantly. This is also true with the increasing internationalization of animal feed providers, live animals, and related avian dietary supplements. Foodborne *Salmonella* infections in human beings are a well-documented public health problem in developed countries. For example, in the United States non-typhoidal *Salmonella* are estimated to be the cause of 19,336 hospitalizations and 378 deaths annually (Scallan *et al.*, 2011). Poultry and egg products are among the foods that are commonly implicated in foodborne *Salmonella* outbreaks.

The potential consequences of *Salmonella* infection can worsen due to emergence of multiple antibiotic-resistant strains, partly resulting from excessive application of antimicrobials in animal feed and treating of those animals (Dione *et al.*, 2012). The virulence of *Salmonella* depends not only on its ability to avoid the host's defenses and invade non-phagocytic cells, but also its resistance to environmental factors (Jones and Falkow, 1996).

During the past decade there has been an increasing appreciation that there are a wide variety of foods that are associated with human salmonellosis, for example fresh produce. However, poultry and poultry products remain a significant contributor to the overall burden of foodborne *Salmonella* infections. One interesting finding was that the incidence of poultry contamination with *Salmonella* is higher in summer (23.6%) than in winter (12.9%), which reveals that designed processing technologies should be sufficiently effective considering the effects of weather in order to avoid human infection by *Salmonella* (Mahmud *et al.*, 2011). Another contribution of human salmonellosis is due to the appearance of multi-resistant strains because of the usage of disinfectants in the hatcheries. A previous study identified the same resistant *Salmonella* strain from different processing plants (Logue *et al.*, 2003).

Campylobacter is another major foodborne pathogen that is often associated with poultry products. Although the bacterium causes gastroenteritis in humans, it is part of the normal microbiota of the avian intestinal tract where it resides without any adverse effects (Shane, 1992). *Campylobacter jejuni* and *Campylobacter coli* cause diarrhea, gastro-intestinal pain and nausea in humans (Zheng *et al.*, 2006). Specific genotypes of *C. jejuni* are a leading cause of Guillain–Barré syndrome, relatively rare but highly serious sequelae that damage parts of the human peripheral nervous system. Scientists have actually identified multiple strains in the majority of flocks of broiler chickens (Petersen *et al.*, 2001; Ridley *et al.*, 2011), indicating that at the stage of chicken infection there was no control of the pathogen.

It currently remains unclear how chickens become infected with *Campylobacter* before harvesting. Scientists have identified several potential vehicles that introduce the pathogen into flocks such as feed, water, rodents, flies, horizontal transmission among birds, and hatchery contamination (Zhang *et al.*, 2011). While it has been reported that *Campylobacter* can be isolated from chicken oviducts, it is generally agreed that *Campylobacter* spp. are not vertically transmitted; chicks are born *Campylobacter*-free. During commercial rearing, colonization of chicks is generally evident 1–2 weeks after hatching. Infection cannot be detected until 1–2 weeks after hatching of the young chicks. It was deduced that pathogen contamination was traced back to hatcheries and that facility layers might infect the eggs.

Campylobacter is commonly found in raw poultry meat. This pathogen is very vulnerable to heat treatment, but if the environment contains a small amount of water with some organic components, the pathogen can then survive for up to several months. Warm-blooded animals are reservoirs for this pathogen (Jones, 2001; Meerburg and Kijlstra, 2007). Considering that this pathogen is vulnerable, many treatments could successfully eradicate the activity of the pathogen in practical production. However, the overall efficacy of these treatments is unclear due to the potential of recontamination, since processing during slaughter and dressing pose significant opportunities for cross-contamination.

Other bacteria such as *Clostridium perfringens*, *C. botulinum*, *L. monocytogenes*, and *E. coli* O157:H7 have also been reported in poultry products (Colles *et al.*, 2008b; Huneau-Salaun *et al.*, 2010), but are less frequently linked to foodborne illnesses. Parasites of poultry and poultry products that can cause human infection are much rarer. In addition to pathogens associated with poultry animals, pathogens associated with human beings including Enterobacteriaceae members are a major food safety concern in handling these animal food products (Kiilholma, 2007).

26.2.2 Pasture poultry

A general public misconception about chicken meat is that free-range or organic chickens are safer than birds reared by conventional production practices. These opinions appear to arise from misinformation related to the effects of large-scale production in high-density enclosed houses, indiscriminate use of antibiotics for the purpose of growth promotion, and the feeding of hormones, again to promote growth. However, studies have recently shown that there was no statistical difference in the prevalence of *Campylobacter* between organic and conventional production chickens. Further, a number of studies suggest a slightly higher incidence of *Salmonella*-positive flocks for organically reared chickens than conventional chicken.

One report indicated that the prevalence of *Campylobacter*-contaminated broiler carcasses was 75.8%, based on results from many locations among European Union countries (EFSA, 2010). Furthermore, organic chickens have a higher percentage of potential biosecurity concerns considering these chickens are raised outside more than 1/3 of their whole life; this might result in a higher genetic diversity in serotypes of *Campylobacter* and *Salmonella*, and a greater potential of being exposed to a broader range of pathogens associated with external sources of contamination (Humphrey and Jorgensen, 2006; Meerburg and Kijlstra, 2007). Chickens contaminated with *Campylobacter* or *Salmonella* might also transmit the pathogens to wild rodents living on these organic farms, and those infected rodents will contaminate other chickens and continue the contamination cycle (Henzler and Opitz, 1992). It should be noted, however, that if conventional farms do not have solid biosecurity programs then they will have the same problems as organic farms.

In addition, organic farms also provide an ideal location for wild rodents taking refuge. Organic farms generally feed animals living on these farms in the pasture which attracts more rodents than conventional closed-off broiler houses; organic farms therefore do not have as many protection measures as those of conventional broiler houses. The number of rodents in organic farms might also be greater than conventional broiler houses because organic farms provide more roughage and straw in or around the farm, more spacious lands for poultry animals to live, and there is the smaller possibility of rodent poisons as many organic farms either use smaller quantities or none at all (Meerburg and Kijlstra, 2007).

Pasture-flocks or free-range flocks typically have a higher microbial risk for several reasons. First, it is difficult to control the flock's exposure to various pests. Pasture-flocks are raised in an open environment, which means the outside birds have greatly increased exposure to potential vectors. For example, flies and other flying insects inside compared to outside poultry houses are often distinctly different species. Wild birds become a critical issue since they often migrate long distances, thereby breaking down geographical barriers to pathogen dissemination. Further, within the geographical locale of a farm, wild birds are likely to visit a variety of sites including other animal facilities, human waste sites, and other potential sources of contamination. Second, eggs from free-range flocks have a propensity to have a higher bacteriological load on the exterior surface of the shell due to floor-laying or contaminated nesting material (Miao *et al.*, 2005). Third, unlike poultry houses which can be readily cleaned and sanitized between flocks, it is much more difficult to achieve sanitary interventions with open range facilities. Therefore, zoonotic pathogens can be transmitted from one generation of poultry to another of the same range (Colles *et al.*, 2008a; Rivera *et al.*, 2011).

26.3 Major sources of pests in poultry

A primary vehicle leading to the colonization of broiler chickens with *Campylobacter* is house flies that gain access to the broiler houses, possibly through ventilation inlets. House flies acquire the *Campylobacter* by visiting sites of poultry and other livestock feces and subsequently transporting it to the broiler house. This scenario will be more acute in the summer, when housefly populations reach their peak. Interestingly, the frequency of *Campylobacter* contamination coincides with this period (Patrick *et al.*, 2004; Hansson *et al.*, 2007).

Wild rodents can also infect broiler chickens by transmitting *Salmonella* and *Campylobacter*. A USDA study reported that approximately 3.7% of house mice in layer house environments were positive of *Salmonella enterica* serovar Enteritidis (Garber *et al.*, 2003). Further, the number of birds positive for *S.* Enteritidis in broiler houses with mice was nearly four times higher than that in houses without mice (Garber *et al.*, 2003). Wildlife is especially prevalent due to the large amount of available water, food, and shelter. Rodents can also further expand the contamination of pathogens in surrounding environment. One example revealed that mice isolates had approximately four times the number of *Salmonella* as isolates from contaminated broiler houses (Henzler and Opitz, 1992). Similar to flies, rodents become infected by these pathogens through feces from various sources such as livestock, wild birds, previous chicken flocks, or their fellow members considering they often live in a large group (Garber *et al.*, 2003).

The pests affecting poultry production can be divided into two categories: premise and ectoparasites pests. The premise pests include darkling beetles ('litter beetles'), flies, moths, cockroaches, and rodents (mice and rats), while the ectoparasites include mites, lice, bedbugs, fleas, and soft ticks. The most common ectoparasite for laying hens is the poultry red mite (*Dermanyssus gallinae*), the vector for transmitting *S*. Enteritidis. The mite transmits *Salmonella* as it feeds from one chicken to another, including transmitting *Salmonella* to chicks (Moro *et al.*, 2009).

26.3.1 Premise pests

26.3.1.1 Beetles ('litter beetles')

There are two species of beetles that are associated with poultry products through manure and litter. One is the lesser mealworm (*Alphitobius diaperinus*), also called the darkling beetle, a pest found in stored grain products. This pest distributes almost all over the world and propagates to numerous populations in the litter of broiler breeder- and grow-out houses, and also exists in the accumulated manure in breeder houses under caged layers or the slats (Axtell, 1999). The other is the hide beetle (*Dermestes maculates*), recognized as a pest of hides, furs, and skins. The larvae and adults of both species are commonly associated with poultry manure and litter (Skov *et al.*, 2004). Generally, the hide beetle is less abundant than the darkling beetle in poultry houses.

Both beetles can result in serious damage as the mature larvae evolve into structural materials, apparently seeking a safe pupation site. The darkling beatle is a carrier, transmitter, and reservoir for a couple of poultry disease-related pathogens including acute leukosis or so-called Marek's disease, fowl pox, many pathogenic *E. coli* serotypes, *Salmonella* species, and tapeworms. The major beetle pest infesting poultry litter and manure is also called the 'lesser mealworm'.

The hide beetle is a beetle with a distinctive warty or bumpy appearance. It can be found worldwide with more than 300 species. The length of hide beetle is 2.5–20.0 mm. The hide beetle is a scavenger and is normally among the last to feed on the remains of dead animals. Both adult and larvae hide beetle eat feathers, fur, and skin of those dead animals; it can therefore transmit foodborne pathogens from those dead animals.

These beetles can become a public nuisance when the manure/bedding from rearing facilities is deposited on nearby fields and the insects subsequently migrate to neighboring residential communities.

26.3.1.2 Rodents

Rodents include rats, mice, squirrels, ground hogs, and other animals that have continuously growing incisors in both the upper and lower jaws. They are not only a nuisance but can spread disease; they therefore need to be controlled. Currently, the Norway rat is the most common rat in poultry farms from reports. This rat lives inside and outside the poultry house in different places such as burrows in the ground, under the foundations, in the litter of breeder houses, under equipment and facilities, or in wood piles and other debris (Mino *et al.*, 2007; Parshad *et al.*, 1987). They need water daily and prefer fresh food, although they can eat most kinds of food. In general, they are nocturnal and come out for food just after sundown.

The house mouse also eats almost any type of food, but normally feeds throughout the day time, feeding the most at sunset and dawn. House mice can live without free water, and they can get free water from the moisture content in their feed (Allymehr *et al.*, 2012).

Both rats and mice can enter a hole that only appears large enough for their head. For mice a 1/4 inch opening is large enough to allow entry. Generally rodents need three basic requirements: food, water, and harborage. The rodent populations cannot grow too much if one or more of the requirements are not meet. Monitoring the rodent population is critical and the best way is by cage type traps, allowing the number of rodents caught over a certain period, 1 day for instance, to be counted.

26.3.1.3 Wild birds

Wild birds can transmit disease and parasites including Newcastle disease, avian influenza, fowl cholera, chicken mites, and mycoplasma. Feral birds should not mingle with our poultry flocks. The most effective way to control wild birds is to check poultry house air inlets and ensure that open windows are screened with $3/4 \times 3/4$ inch wire meshes. The other measures include cleaning up any feed spills and accumulated water outside the building, cutting grass and weeds to prevent nesting, and searching for possible nests and roosting areas and removing them in time. Some mechanical frightening facilities are available, but the value of such devices are limited (Darre and Rock, 1995). In addition, trapping birds may require permission and is therefore not a good long-term solution (Axtell, 1986; Spackman, 2009).

26.3.1.4 Flies

Poultry manure which has a certain amount of moisture content provides an ideal habitat for the formation of large populations of the house fly, *Musca domestica Linnaeus* (Insecta: Diptera: Muscidae) and closely related species of 'filth flies' (Szalanski *et al.*, 2004). In addition to concerns about flies being a vehicle for the transmission of infectious agents, they also can be a significant nuisance by disturbing workers and affecting nearby community residences and businesses.

The house fly is the common fly pest with the most persistence. It does not bite poultry but can transmit poultry disease. To control house flies, manure management is the most important strategy. In history, it is considered to have contributed to the spreading of the virus leading to the Newcastle disease outbreak in 1970s (Watson *et al.*, 2007). Today, concerns about flies are mainly due to their nuisance characteristics. Although limited numbers of flies can travel up to several miles from their breeding location, most of them are limited to within several hundred yards from their breeding sites. On the poultry farm, adult flies feed on various materials such as manure, broken eggs, spilled feed, and decaying organic materials from surrounding sources.

Another category of flies are fruit flies. They are often live in places where food has been rotted and fermented. Adult fruit flies are about 1/8 inch long and generally have red eyes. Fruit flies lay their eggs close to the surface of wet organic materials. They are primarily nuisance pests, but can potentially contaminate food with bacteria and other disease-producing microorganisms.

26.3.2 Ectoparasites

26.3.2.1 Mites

The northern fowl mite, *Ornithonyssus sylviarum* (Canestrini and Fanzago, Acari: Macronyssidae), is widely distributed and the most common ectoparasite. In tropical areas, the most common species may be the tropical fowl mite, *O. bursa* (Berlese). However, there are no major differences of the biology, behavior, and control methods between the two species. Fowl mites are common on chickens, turkeys, and all kinds of wild birds; occasionally they may be found on rodents, but they do not reproduce on rodents (Rassette *et al.*, 2011).

Fowl mites are a common problem in caged layers and breeder flocks. This problem is related to the type of housing and the extent of co-habitation of these cages and flocks. For broiler turkeys and those grown outside houses, fowl mites are not critical considering the very short periods these turkeys stay within the house.

Another important type of mite influencing poultry production is the genus *Dermanyssus* (Acari: Dermanyssidae) with *D. gallinae* (De Geer); this mite is referred to as the chicken mite, red mite, or roost mite. The biological characteristics of the chicken mite are significantly different to those of fowl mites. *Dermanyssus* chicken mites are a potential problem in current poultry production systems because they are easily accessible to birds and have ample places for them to hide within the house, which is helpful for the life cycle of the mite. Chicken mites are often found in broiler breeder houses since the litter, nest boxes, and slats provide a favorable environment. *D. gallinae* is a critical ectoparasitic pest of poultry and it is a potential pathogen vector. It was found that the high prevalence of *D. gallinae* in layer flocks is linked to the presence of *Salmonella* spp. on infested poultry farms (Hamidi *et al.*, 2011).

Avian resistance to an ectoparasitic arthropod and the corresponding costs to the parasite of that host defense for the northern fowl mite have been studied previously (Owen *et al.*, 2009; Birkett *et al.*, 2011; Rassette *et al.*, 2011).

In Europe, *D. gallinae* is the most important ectoparasite of laying hens economically. Due to pesticide resistance and product withdrawal, control of *D. gallinae* has been hampered. Scientists have proposed integrated pest management (IPM), which is often applied in controlling agricultural pests, as a solution. Essential oils such as garlic and thyme might serve as effective *D. gallinae* acaricides and repellents. Other strategies for controlling *D. gallinae* are using predators and fungi and other husbandry techniques such as adjusting temperature and lighting regimes in poultry farms. In general, potential and promising techniques for controlling *D. gallinae* include novel acaricides, vaccines, biological control using natural enemies or entomopathogenic fungi, animal husbandry, and IPM (Mul *et al.*, 2009).

26.3.2.2 Fleas

In poultry houses, fleas (Siphonaptera) are not common creatures; under specific conditions they can however be abundant ectoparasites. In most cases, fleas are commonly present when the poultry houses are used for breeding and after grow out. The most popular species are cat flea, *Ctenocephalides felis* (Bouche), and European chicken flea, *Ceratophyllus gallinae* (Schrank) (Axtell, 1999). One additional species is the human flea, *Pulex irritans* (Linnaeus), which could also be found infesting flocks. Fleas may enter poultry houses through infested rodents, cats, or wild birds (Axtell, 1999). Bubonic plague is a disease of rodents caused by bacterial *Yersinia pestis*. Humans and other animals can become infected via infected rat fleas. Human beings, for instance, can get the plague from being bitten by rodent fleas that carry bacterial *Y. pestis* (Microbiology, 2013).

26.3.2.3 Ticks

Ticks are associated with old poultry production systems. In modern poultry production, there are not many cases of ticks in poultry products. The two most common species of ticks viewed as poultry pests are fowl ticks (Acari: Argasidae), *Argas persicus* (Oken), and *Argas radiatus* (Raillet) (Medley and Ahrens, 1970). Wild birds are usually the source of infestation. Most infestations occur in breeder houses where the environment is most compatible with ticks.

More evidence has demonstrated that ticks should be considered as a potential and emergent pest and pathogen vector to human beings and animal hosts such as rural poultry (Evans *et al.*, 2000; Malsure and Kolte, 2001).

26.4 Important poultry-related diseases associated with pests

26.4.1 *Salmonella* and *Campylobacter*

In general, wild birds and mammals are recognized as the main reservoir for *Salmonella* and *Campylobacter* in poultry house and poultry products. They are warm-blooded animals and carry both bacteria in their intestinal tracts without any detectable clinical symptoms of disease in most cases (Blaser *et al.*, 1983; Meerburg and Kijlstra, 2007). Many epidemiology reports have demonstrated that infected wild birds or mammals serve as vectors and infect food animals by transmitting the pathogens *Salmonella* and *Campylobacter*. The impact of *Salmonella* spp. in poultry production is of particular importance because it is closely related to human health, affecting both food safety and poultry production. The behavior of *Salmonella* spp. is a model for elucidating general pathogen persistence in poultry farming or processing environments; however, most of what we know about this pathogen in the poultry production environment comes from indirect evidence (Park *et al.*, 2008).

Numerous projects have studied *Salmonella* in poultry with the ultimate goal of developing effective strategies to minimize *Salmonella* contamination of raw poultry meat. However, although academic, industry and government regulatory agencies have spent decades studying the problem, there has been little if any decrease of in the incidence of human salmonellosis and *Salmonella* is still present in a significant portion of raw poultry (Cox *et al.*, 2011). Table 26.1 lists examples of risk categories and risk factors that are associated with *Salmonella* contamination in poultry. The achievement of a meaningful reduction in the prevalence of zoonotic agents such as *Campylobater* and *Salmonella* requires both intervention-based and prevention-based controls and methods for monitoring the effectiveness of those efforts. Key to such efforts is identifying and understanding the sources and the mechanisms by which *Salmonella* and *Campylobacter* microorganisms colonize and thrive within poultry and poultry rearing environments. Such efforts are needed to provide an objective means of evaluating the status of poultry farms, and making farmers aware of relevant farm management techniques (Wilke *et al.*, 2011).

Animals, rodents, and pests are recognized as critical sources of *Salmonella* and *Campylobacter* infections and cross-contamination. Rodents are one of the major sources of cross-contamination and infection of *Salmonella*. A previous report demonstrated that 3-week-old chicks were infected by artificially *S.* Enteritidis-infected mice (Davies and Wray, 1995). Spreading of pathogens in the environment can be increased significantly after exposure by rodents: three times more *Salmonella* were isolated from mice than those from the environment contaminated with poultry wastes (Henzler and Opitz, 1992). It has therefore been suggested that rodents continuously reintroduce unstable and invasive phenotypes to the poultry environment (Van de Venter, 2000; Meerburg and Kijlstra, 2007). An increased rate of introduction of *Campylobacter* to broiler houses is also associated with the presence of rats in poultry farms (Kapperud *et al.*, 1993; Liebana *et al.*, 2003). A study reported that 87% of rat

Table 26.1 Comparison of the reported identified main risk categories and factors of *Salmonella* introduction among findings. Adapted from Wilke *et al.* (2011) (NA: not available).

		Reference			
Risk category	**Risk factor**	**Rose *et al.* (1999)**	**Poppe (2000)**	**Snow *et al.* (2010)**	**USDA (2010)**
Poultry house management and poultry house state of repair		Important	NA	Important	Moderate
Delivery and collection of birds		Important	NA	NA	Important
Poultry house hygiene		NA	Moderate	Important	Important
	Disinfection foot dips	NA	NA	Important	Moderate
	Disinfection housing equipment	NA	NA	Important	Important
Pest control		Moderate	Important	Important	Moderate
	Rodents	Moderate	Important	Important	Moderate
	Beetles	Moderate	NA	NA	Moderate
Feed management		Important	Important	NA	Important

fecal samples tested positive for *C. jejuni* (Kasrazadeh and Genigeorgis, 1987). Similar phenotypes of *Campylobacter* were isolated in mice intestines as well as in the environmental samples collected from the poultry farm and production sites (Hiett *et al.*, 2002).

Very often *C. jejuni* was transmitted directly from poultry to humans. Due to this transmission, researchers are considering alternative intervention strategies for controlling colonization and cross-contamination of pathogens in poultry production. It is widely accepted that interventions during poultry production potentially provide the greatest opportunity to reduce the risk of foodborne infections. Application of bacteriocin is one of the strategies to prevent *C. jejuni* transmission during animal production. Application of therapeutic bacteriocin can also reduce the colonization of *Campylobacter* in poultry gut from $>10^8$ CFU g^{-1} of cecal materials to below the detection limit or to low levels (Svetoch and Stern, 2010).

Current pre-harvest methods for reducing *Campylobacter* contamination in poultry production are focused on farm biosecurity measures, decontaminating litter, and providing feed with compounds to inhibit *Campylobacter* and treated drinking water, but these are not enough. Some novel strategies, for instance to control *Campylobacter* at pre-harvest levels, are currently under development. These strategies include probiotics administration, vaccination, antibiotics combined with molecules for preventing the emergence of antibiotic resistance, and antimicrobial alternatives such as bacteriophages and bacteriocins (Pasquali *et al.*, 2011).

The Food Safety and Inspection Service (FSIS) is one of the major agencies in the United States responsible for the safety of poultry products. Control of poultry contamination via digestive tract contents is a major focus of regulatory standards. Control of contamination with feces or ingesta is directly linked to improving microbial safety of poultry and poultry products. Improvement of processing technologies, including reprocessing poultry on a production line that can remove feces and ingesta, should be the focus to improve microbiological safety of poultry products (Rasekh *et al.*, 2005).

The FSIS encourages development of innovative technologies to prevent and improve microbial safety for poultry. In the future, the following aspects should be considered to improve the safety of poultry and poultry products: practical evisceration techniques that do not rupture the crop or intestine; application of appropriate processing practices for decreasing cross-contamination risk via digestive tract contents; and development of alternative technologies or methods to evaluate microbial safety (Rasekh *et al.*, 2005).

26.4.2 Coccidiosis of poultry associated with pest

Coccidiosis has been recognized as of one of the major old and chronic causes of poor performance and lost productivity in poultry. The disease is due to protozoan parasites known as *Eimeria*. *Eimeria*'s oocysts are commonly found in the poultry farms and its surrounding environment. It should be noted that these protozoan parasites are strictly pathogenic to poultry, no other animals are affected (Chapman *et al.*, 2010). Coccidiosis affects mainly the intestinal tract of birds. Coccidiosis decreases animal production and entails huge treatment and prevention costs (Peek and Landman, 2011). Due to this disease, many poultry farmers face significant economical difficulties. Currently, most knowledge of coccidiosis has been obtained from chickens.

Monensin is an effective and specific medicine for preventing and curing coccidiosis. Unlike growth-promoting antibiotics, monensin specifically targets the *Eimeria* parasite. Application of monensin in poultry has been widely used for the last 40 years and is recognized as the most effective available compound. Other alternative medications for coccidiosis are under investigation, as it is highly likely that continuous use of monensin will allow the parasite to develop a natural immunity to the compound (Chapman *et al.*, 2010).

26.5 Current practices of pest control in poultry

The size of a pest population in and around poultry houses depends on abiotic and biotic factors. Abiotic factors refer to conditions of the environment. The most important are temperature and the habitat's physico-chemical properties. Biotic factors refer to the effects of living organisms which include natural enemies such as predators, parasites, pathogens, and competition among the species.

In general, three factors including housing type and management, waste management, and flock management are involved in poultry production and shaped the fundamentals of the abiotic and biotic factors. It should be emphasized that these factors are interrelated (Carey *et al.*, 2004).

26.5.1 Housing type and management

Housing type and management are dependent on the type of birds, budget, and the specific preferences of farmers. Appropriate air flow is necessary to dry the manure and litter to reduce fly breeding and ammonia production (Arends and Robertson, 1986; Kathiresan, 2007; Harrington *et al.*, 2011). For open-sided houses, air flow could be significantly improved by cutting grasses and weeds around the houses. That also reduces rodent invasion due to reduced harborage. The houses should be built on graded land to facilitate easy drainage of rainwater. A poor drainage system around the poultry houses causes fly and other pest problems and structural damage of the foundations. Proper housing and management can reduce the production cost and control pest invasion significantly (Arends and Robertson, 1986; Kathiresan, 2007; Harrington *et al.*, 2011).

26.5.2 Waste management

Waste management refers to the strategy of handling manure, litter, and dead birds. Appropriate housing is the best way to dry the manure, and can also help in the removal of manure for spreading on land and to reduce fly invasion. To save energy, a more common disposal method is to flush the manure to a lagoon and recycle the lagoon water for flushing. Proper design and management of a lagoon is crucial in preventing mosquito breeding (Scovill, 1963). Deep lagoons which are free of vegetation at the steep sides of the land could significantly decrease or totally eliminate the mosquito breeding and infiltration to the farm houses. In both breeder and grow-out houses, the litter may contain a mixture of feces, spilled feed, feathers, wood shavings, or other dry materials. Caution is needed regarding excess spilled feed; this is not only economically undesirable, but also creates a favorable environment for beetle production. Although bird mortality is unavoidable, dead birds should not be left in the house or piled just outside the houses. This could promote the insect invasion by promoting pest production such as blow flies. Currently, accepted popular methods of disposal of dead birds are incineration, composting, and burial (Sander *et al.*, 2002; Blake, 2004).

26.5.3 Flock management

Flock management refers to the administration of the general health of the poultry such as feed and water supply methods and their consumption. Too much water consumption by the poultry, and improper nutrition or gastrointestinal diseases, can cause fluid feces characterized as wet manure or litter and facilitate fly invasion and production. Pest problems are often recognized as an indicator of inappropriate housing, waste, and flock management. These management practices strongly affect the abiotic factors such as moisture content, humidity, temperature, and conditions of the manure and waste. These mal-practices also have effects on the biotic factors. The natural pest and parasite populations are influenced significantly by abiotic conditions. In particular, the condition of the manure or litter affects the habitat and survival abilities of parasites, predators, and pathogens that in turn affect populations of pest species (Guerin *et al.*, 2007; Halvorson, 2009).

Several methods can be applied for controlling and eliminating rodent infiltration in the broiler houses. All places that a mouse can enter into the broiler houses should be blocked off. For instance, broiler sidings and doorways should have an appropriate thickness and structure for preventing rodents from entering into the houses. Other measures such as traps and rodenticides can also be applied to eliminate the risk of mice invasion. In an uninhabited house, fumigants could also be considered to eliminate their in-house hiding places (Brown *et al.*, 2002).

Many measures can also be applied for controlling poultry mites (*D. gallinae*). The most critical for preventing contamination by poultry mites is to keep the broiler houses clean. Red poultry mites spend most of their lives on the birds for blood sucking. Currently, the most common measure against red mites is spraying acaricide insecticide in empty broiler houses. However, long-term use of this method could result in an increasing resistance to this poultry mite. Other methods should be considered, including utilizing predatory insects such as spiders, microbial insecticides in the form of exotoxins from other microorganisms, feeding deterrents, and silica toxins (Huber *et al.*, 2011; Lesna *et al.*, 2012).

Natural biological control such as pest predators can be placed within the manure to control mites, beetles, and parasites commonly found in the poultry houses. This biological control is more practical in cage layer operations since predator populations can be increased. This type of biological control results in the suppression of fly production. To save the beneficial insects, it is critical to avoid spraying insecticides directly on manure except occasionally (Lesna *et al.*, 2009).

Parasitic wasps could be placed to add to the naturally occurring wasp populations. The wasp larva originates from the eggs and feeds on the fly pupa, thus reducing the fly population. When farmers choose this method to control flies, they should not spray insecticides in the poultry house. Small predaceous beetles, or hister beetles, are available from most biocontrol producers and can be released in poultry houses for natural control. If sources are clear, predators and competitors can be used to facilitate their co-existing benefits (Prasad and Snyder, 2004).

Additional methods include the use of adult fly traps, which use sex pheromones or food lures to seduce flies into the traps. Zapper traps utilize light to entice flies and then electrocute them. Other light traps may entice flies to glue boards and flies can be trapped when they touch the board to eating or rest.

Chemical control can also be performed through applying baits, contact sprays, residual and bait sprays, or larvicides. By appropriate management of manure and litter, periodical maintenance of drinker lines, and sufficient ventilation, the environment of a poultry house can be unattractive to flies. Understanding the life cycle of various flies and knowing the most effective control strategy for each stage of fly development can allow producers to take useful measures to prevent fly outbreaks (Axtell, 1986).

26.6 Promising pest control strategies

Microbiological risk assessment (MRA) has been recognized as a key strategy of food safety associated with poultry meat products in worldwide management. The methodologies and critical issues such as uncertainty, model complexity, and model validation are important for the study of MRA (Kelly *et al.*, 2003).

Poultry safety is relevant for both pre- and post-harvest levels of production and there are many critical steps associated with safety measures of poultry products. Figure 26.1 describes the steps involved in farm-to-fork exposures and microbial risk management for poultry and poultry products. Multidisciplinary research is required to characterize and improve the sustainability and quality of poultry production (Jez *et al.*, 2011).

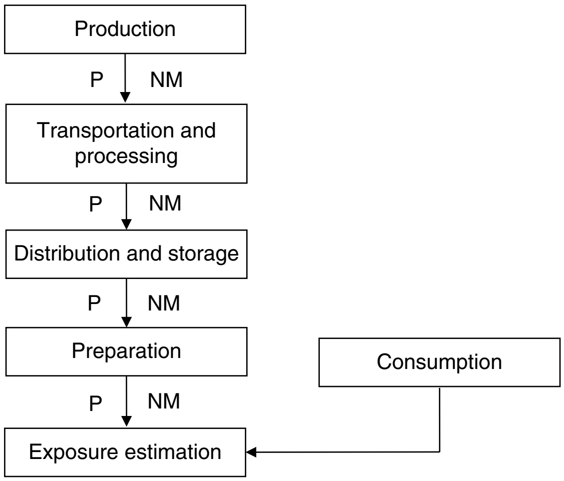

Figure 26.1 Steps involved in farm-to-fork exposure assessment for poultry meat products (P: prevalent; NM: number of microorganisms). Source: Hartnett *et al.*, 2003. Reproduced with permission of WSPA.

26.7 Conclusion and future outlook

Pest control in poultry farms is a prerequisite for biological safety; controlling pests with appropriate chemicals or antimicrobials is essential for chemical safety. Biosecurity is always a primary consideration to prevent colonization and cross-contamination of human pathogens in poultry with potentially disease-related organisms and pests into the facility. Optimal number of flocks, housing, and waste management procedures should be continuously practiced and monitored to assist in controlling pest populations and to prevent invasion by flies, parasites, and other predators. When pest levels are found to be unacceptably high, additional measures should be taken to improve the execution of management practices. The application of insecticide must meet the requirements of the poultry management practices and must not negatively affect the health and environment of flocks in the farm.

Chemicals may sometimes be needed for fly control such as residual spray or insecticide–bait mixtures to lower the adult fly population to a specific acceptable level. However, these chemical applications must be performed with minimal contamination of the manure to maintain fly parasites and predators at the natural populations (Axtell, 1986; Ellis and Scatcherd, 2007).

Many pests on poultry farms can be controlled with proper measures. It is critical to use clean broiler houses to prevent pest invasion and bird contamination. Floors should be cleaned after every flock passes through and properly monitored for the presence of pests. However, it should be noted that the majority of the reported contaminants from pests were not derived through direct contact, but indirectly from contaminated feed and water (Renwick *et al.*, 1992).

Appropriate biosecurity measures should be applied to restrict the amount of contaminant that can spread in poultry farms. Workers should wear appropriate hygiene clothing when dealing with broiler houses (Cardinale *et al.*, 2004). A large portion of *Campylobacter* and *Salmonella* spreading is via the misuse and lack of appropriate clothing and boots and appropriate application of disinfectants in farm practices (Cardinale *et al.*, 2004; Todd *et al.*, 2007). It has been reported that factors contributing to the risks of *Salmonella* contamination in a broiler farm include: neglecting to treat the flock for any diseases; unhygienic conditions in the house; dry conditions under the slats; and frequently walking through the house to pick up dead birds (Volkova *et al.*, 2011).

In addition to temperature control and its role in colonization and transmission of *Campylobacter*, the control of flies is essential, especially during the summer season. A fly screening study revealed that effective control of flies in broiler houses significantly decreased the colonization and contamination of *Campylobacter* compared to the control group (Hald *et al.*, 2007).

Evaluation is the last part of any good integrated pest management (IPM) program. The outcome of the pest control program should be constantly evaluated. This can be performed in several ways by counting pests before and after treatment, rating comparative damage, comparing costs of pest control periodically, recording pesticide usage, and evaluating its effectiveness. Once pests are under control, it is just a matter of maintaining that level and continuing the monitoring program. Remember that pest problems never can be totally eradicated; they must however be controlled at a manageable level.

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