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Campylobacter, Salmonella and *Escherichia coli* Food Contamination Risk in Free-Range Poultry Production System

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Abstract

Livestock such as poultry is consumed as food worldwide and it constitutes one of the main protein sources for diners, as well as an important source of revenue generation for farmers. Poultry meat production chain identifies a significant role of the farm to folk. Most often, the systems used in poultry production can result in a higher prevalence of *Campylobacter, Salmonella, and Escherichia coli* contamination, leading to adverse health effects with detrimental consequences. The method of poultry keeping plays a significant role in the poultry meats' outcome and its food safety standards. Farmers attempt to develop new poultry operations, however, there are two main possibilities; to operate within the present vertically integrated system which is incredibly good for disease prevention and to develop independently, or a smaller operation that is more animal friendly. This article reviews the available research on the impact of free-range poultry production systems on food safety, most importantly the prevalence and control of *Campylobacter, Salmonella* and *Escherichia coli* in free-range production systems. The results suggest a conflicting view when bacterial loads of poultry meat from conventional and free-range systems are compared. Studies have shown increased bacterial loads in a free-range production system.

Keywords

Free-Range, Poultry, *Campylobacter, Salmonella, Escherichia coli,* Contamination

1. Introduction

Statistics drawn from the World Health Organization [1] revealed that 420,000 people die yearly from 600 million cases of foodborne diseases. Unfortunately, 30% of those recorded deaths are among children under the age of 5 years. Recording the burden of foodborne illnesses is harder than it seems as some chronic illnesses, like cancer, kidney or liver failure resulting from the consumption of contaminated foods appear to require a longer time to indicate. While the severity and impacts of foodborne diseases differ from country to country, a number of these challenges are common to any or all countries [1]. As an example, statistics from the Government of Canada showed that there are 11,600 hospitalizations and 238 deaths yearly as a result of foodborne illness [2].

Studies have shown that food from animal origin is implicated to be a crucial source of human infection and transmission mode has been through handling and meat consumption [3]. Countries like Canada, the US and Japan have implemented routine evaluation of eggs before retailing [4] which is sort of uncommon in developing countries. Enterobacteriaceae group was the main group of bacteria isolated from 160 table eggs in a study conducted in Grenada [4]. Consequently, more consumers are now conscious of issues of safety related to food consumption and public perception is now on microbial integrity.

Food safety and the impact on human health have changed the concept of food and made it undergo a radical transformation in recent times. Consumers' attention is being drawn to birds raised without the utilization of antibiotics. Consequently, there's an increased sensitivity toward the moral and cultural aspects of animal-sourced foods. Animal welfare and human health continually fuel the interest in animal-friendly farming systems [5]. As a result, the conventional cage-system is being replaced with cage free, organic and free-range production systems so as to boast the welfare of the animals and modify the product quality [5].

In the past decades, conventional systems were adopted worldwide thanks to efficient disease prevention, especially disease causing micro-organisms [6]. Nevertheless, a more suitable and ideal alternative for egg production and laying hen welfare is a free-range system [7]; however, this technique is related to microbiological implications which remain controversial [8]. Although *Clostridium perfringens, Salmonella, Listeria, E. coli, Campylobacter and Vibrio vulnificus* are major bacteria that cause foodborne illnesses, *Salmonella, E. coli,* and *Campylobacter* are the ones closely associated with poultry [9] [10]. Therefore, this paper seeks to answer a pertinent question "is free-range safe?" Also, the paper examines the prevalence or bacterial loads of *Salmonella, E. coli,* and *Campylobacter* in free-range production systems.

2. Methodology

Literature search within specific databases like Scopus, Science direct, PubMed as well as Google Scholar, springer and web of science were conducted from January to March, of which a total of 375 original articles were found. Keywords used include Free-range, *Salmonella, Campylobacter, Escherichia coli,* food safety in free-range, microbial contamination in free-range, prevalence of *Salmonella, Campylobacter* and *Escherichia coli*. The review carried out placed no lower limit on the publication dates and an upper limit of 2020. However, only 80 articles including government documents were included in this review. The three reviewers independently screened abstracts of studies and disagreement were settled through consents. Eligible studies (that assessed the contamination, prevalence and control of *Salmonella*, *Campylobacter* and *Escherichia coli* in free-range production systems) were extracted independently by reviewers. Non-English review articles were excluded. A handful review papers were however referenced for general knowledge.

3. Free-Range and Microbial Contamination

3.1. Is Free-Range Safe?

In countries like the UK, Denmark and Australia where it's possible to practice free-range systems for most of the year, consumers are interested in this animal-friendly system of production. Moreover, natural and ethical concerns keep making free-range production systems more popular [11]. As a result, there has been a decline in the practice of the standard cage system. In 2014, Australia witnessed an enormous eggs production worth $1.7 billion and the free-range production system makes up about 38% (AECL, 2014). Free-range is different from cage-free in that free-range system birds are housed in sheds but are provided access to an outdoor range [12]. Recently, it's been found that hens are plagued by different kinds of stressors in free-range when compared with the hens within the barns and cage systems [13]. Consequently, these challenges negatively impact the welfare and productivity of hens [14]. There are different styles of welfare measures, such as weight, cannibalism, vent pecking, feather pecking, and external visual egg characteristics which are being employed to establish hen welfare [14].

Currently, there's an increasing interest of consumers and welfare advocates in free-range as the best alternative for egg production while overlooking its negative welfare aspect on the hens. One other important aspect of the free-range system is that it increases the possibility of disease transmission, parasite occurrence, injury and predation [13] [15]. On the other hand, free-range systems allow for the full expression of the hen's behavior and freedom [14], including but not limited to perching, experience natural light, foraging, dustbathing and many more [15].

A report has shown that eggs and egg products consumption can be attributed to the major food poisoning occurrences [16]. For the safety of eggs, total bacteria populations are an indicator employed [17]. The eggshell is quickly colonized upon production and therefore the bacteria travel from the shell cuticle to the pores and eventually make it into the albumen and yolk. With this possibility, it's vital to work out the bacteria count in different parts of the egg, including the surface and the internal contents. Currently, the extent of pore contamination of *Enterobacteriaceae* is unknown thanks to lack of research [18]. *Enterobacteriaceae* family is a crucial family, including *Salmonella*, leading the reason for the main foodborne illnesses [19]. *Salmonella* and *Campylobacter* are the 2 bacteria leading to food infections in humans. Although little is thought about *Campylobacter's* reference to the contamination of eggs, however, infections from the consumption of broiler chickens are commonly linked to *Campylobacter* [20]. With the adoption of free-range production systems and the importance of food safety, it is necessary to look at the prevalence of common bacteria (in the free-range system) accountable for foodborne illnesses.

3.2. Campylobacter

The most frequently reported gastroenteritis is chiefly caused by *Campylobacter*. *Campylobacter* remains the leading cause of bacterial foodborne diarrheal diseases worldwide [21]. An early study reported that the consumption of poultry and poultry products accounts for 50% - 70% of human campylobacteriosis [22]. As a result, poultry, especially the free-range systems, is known as the largest reservoirs with the easy transmission of *Campylobacter* to humans causing bacterial gastroenteritis [23] [24]. While *Campylobacter* is widely known to come from poultry, studies have shown that high levels are found in broilers; both in broiler carcasses and retail chicken [25]. Friedman *et al.* (2000) have shown that *C. jejuni* contributes to 85% of the illness followed by *C. coli*. It is important to note that the transmission of this organism to human is by horizontal route, however, it can be transmitted through both horizontal and vertical routes.

The existence of *Campylobacter* in the intestinal tract of poultry is that of a commensal organism. *Campylobacter* spp. rapidly colonize the cecum and colon of birds and a rupture or leak of the intestinal tract during processing could contaminate the carcass [21]. Most times, *Campylobacter* spp. survive and proliferate in favorable environment such as the cervices and channels of skin. The bacteria can survive frozen conditions under the microenvironment of the skin. Many acute campylobacteriosis outbreaks have been reported both in developed and developing countries as a result of the consumption of chicken and chicken meat products. Most of the commonly reported cases of campylobacteriosis are in children, old and immuno-suppressed patients [21].

The Prevalence of Campylobacter in Free-Range Systems

In France, free-range production accounts for 60% whole broiler carcasses consumption and about 15% of the total production. In Spain, a study reported the isolation of *Campylobacter* in 70.6% of 60 flocks from 34 free-range broiler farms [26]. In Chile, a survey of 50 free-range broiler carcasses reported 34% prevalence of *Campylobacter* [27]. Also, about 95% to 100% of the carcasses from free-range tested in the USA were contaminated with *Campylobacter* [28]. A longitudinal survey on six free-range farms in Belgium reported 100%, 66.7% and 33.3% *Campylobacter* prevalence in the summertime, spring and winter respectively [29]. In a study in Greece, meat samples from standard and free-range farms had no significant difference in *Campylobacter* contamination between the two types of production (28.7% vs 29.4%) [30]. In another study in the UK, 95% to 100% of the 28 organic and free-range flock examined were contaminated with *Campylobacter* while standard flocks had 55% contaminated with *Campylobacter* [31]. In a study conducted in South Africa, the level of *Campylobacter* caecal carriage in different traditional and industrial production systems were compared. The *Campylobacter* prevalence in the different systems was 68%, 47%, 47% and 94% in rural backyards, commercial free-range flocks, industrial standard broilers and industrial laying hens respectively [32]. All these studies revealed the high prevalence of *Campylobacter* in free-range systems, especially in bird's infection or carcasses contamination in the USA, UK, Spain, and Belgium.

3.3. Salmonella

As reported by EFSA & ECDC (2015), *Camylobacter* and *Salmonella* are the main pathogens responsible for food-borne illnesses in Europe [9]. Globally, *Salmonella enterica* is one of the frequently reported causes of foodborne illnesses, such as human gastroenteritis. *Salmonella* quickly colonize the gut and causes inflammation and diarrhoea [41]. As of 2010, *Salmonella* spp. accounts for 93.8 million cases of gastroenteritis and about 155,000 deaths globally every year [42]. Globally, the outbreaks of human salmonella are frequently linked to the consumption of contaminated food products of animal origin, particularly egg and egg products [43]. Two common types of salmonella that have dominated the epidemiology of *Salmonella* are *Salmonella enteritidis* and *Salmonella typhimurium.* These two *Salmonella* types are the most common causes of human salmonellosis [44]. Moreover, *Salmonella enteritidis* is predominant and commonly isolated from eggshell and egg contents. This serovar is frequently linked to foodborne outbreaks in the USA and UK [45]. On the other hand, except for overseas travel, no human infection is linked with this serovar in Australia and New Zealand, however, *S. typhimurium* is the predominant cause of foodborne illnesses [46] [47]. Since Australia and New Zealand have strict regulations and surveillance strategies on animal importing, *S. enteritidis* is not endemic in the poultry flocks [48].

Although proper egg cooking will destroy most bacteria present, however consuming raw or lightly cooked eggs will result in a high risk to human health. With the estimated presence of *Salmonella* around eggs, 1 in 20,000 [49], the risk of foodborne illness, in general, is low for people consuming eggs. However, some regions have high risk of foodborne illness from consuming lightly cooked eggs.

3.3.1. The Prevalence of Salmonella in Free-Range Systems

Although there are limited studies regarding the contamination of free-range birds, the development of free-range production is low. A survey of 196 flocks in four European countries; Italy, Lithuania, the Netherlands, Germany, found that in a standard production there was a *Salmonella* prevalence of 29%, 20%, 11% and 0% in Lithuania, Italy, the Netherlands and Germany respectively, while free-range flock had a prevalence of 1% in Italy and 7% in the Netherlands (Lithuania and Germany had no free-range test) [34]. In Spain, a study reported the isolation of *Salmonella* in 2.9% of 60 flocks from 34 free-range broiler farms [26]. In Chile, a survey of 50 free-range broiler carcasses reported 0% prevalence of *Salmonella* [27]. Also, about 50% to 100% of the carcasses tested in the USA were contaminated with *Salmonella* [28]. All these studies revealed the prevalence of *Salmonella* in free-range systems, especially in bird's infection and eggs contamination. Except for the USA, the prevalence of *Salmonella* in most countries is low when compared with battery cage systems.

3.3.2. Mechanism of Egg Contamination

Studies have reported that the reproductive organs of laying hens are quickly colonized by both *S. enteritidis* and *S. typhimurium* and consequently contaminate eggs and contents. While *S. enteritidis* is the most common cause of foodborne illness in most parts of the world, *S. typhimurium* is the major cause of foodborne illness related to egg and egg related outbreaks in Australia [47] [50]. There are several factors responsible for internal and external contamination of egg during poultry production such as vaccination, flock size, flock age, feed, egg production process, storage, handling of eggs, cleaning and disinfection routines [6]. Consequently, control measures may be extremely difficult to implement. As stated earlier, eggs can be contaminated via two routes; vertical or horizontal. The colonization of the hen's reproductive organ (ovary and oviduct) before shell formation results in vertical transmission while the penetration of the eggshell membrane by *Salmonella* after the egg is laid results in horizontal transmission [51].

The relationship between eggshell contamination and increased *Salmonella* shedding in faeces has been reported [52]. *Salmonella* shedding and egg contamination increases in laying hen with the presence of environmental stressors. The production cycle of hens encounters many stress events that negatively impact both the cellular and humoral immunity of the hens [53]. As birds experience immuno-suppression from stress, they become more susceptible to *Salmonella* infection which usually increase shedding of Salmonella in the feces [54]. A common stressor that may induce *Salmonella* shedding in feces and eggs is the onset of lay [52] [55]. Gole *et al.,* (2014) in a longitudinal survey revealed that the highest shedding of Salmonella coincided with onset of lay indicating that the *Salmonella* load in feces was highest (82.14%) at 18 weeks of age when compared with a sharp reduction of 38.88% and 12.95% at the age of 24 and 30 weeks respectively. Higher estimates may be possible for birds in a free-range system as they are exposed to more environmental stress. The risk of egg contamination has been demonstrated to be higher when birds are infected at the onset of lay (Okamura et al., 2010).

3.3. Egg Contamination and *S. typhimurium* Infection

Australia witnessed a 6% increase in egg production during 2014-2015 compared with the previous year of 5 billion eggs. This paved way for 3% increase in per-capita egg consumption compared with the previous year of 221 eggs per year [56]. The significant challenge to the poultry industry remains egg contamination by *Salmonella* spp. Between 2001 and 2011, the number of *Salmonella* related outbreaks increased significantly in Australia. Most of the time, the outbreaks raise public health concerns as more than 3200 people have been affected and hospitalization rate hits 20% [57] [58] [59]. All these egg-associated outbreaks in Australia are linked to different types of *S. typhimurium* [47]. Also, the country witnessed about 128 outbreaks of *S. typhimurium* related to the consumption of raw or undercooked egg and egg-related products in different food preparation settings between 2011 and 2014. About 2343 cases with 347 hospitalizations resulted from these outbreaks. Together, *Salmonella typhimurium* definitive types DT170/108, DT9 and DT135/135a were linked to 69% of 121 egg related outbreaks. About 69.42% of the outbreaks were from commercial food providers such as restaurants, commercial caterers, takeaways and bakeries in the three most populous states in Australia; New South Wales, Queensland and Victoria. Only 26% of these outbreaks occur in private homes with lower number of individuals when compared with commercial settings [57] [58] [59].

3.4. *Escherichia coli*

Escherichia coli is one of the major food contaminants and people get exposed to it when fresh food products are cooked inadequately or from cross-contamination of uncooked food during meal preparation. *E. coli* can be regarded as the most studied bacterium [60] with primary and secondary habitats being the intestinal tract of warm-blooded animals. In poultry, within 24 h after hatching, *E. coli* colonizes the lower digestive tract [61]. The ingestion of *E. coli* can lead to three potentially adverse consequences such as the establishment and persistence of a strain capable of causing a subsequent extraintestinal infection; ingestion of diarrheagenic strain could lead to possible disease; and it can also lead to mobile genetic elements and antibiotic resistance determinants that might transfer to other strains resident in the host [62].

In Nigeria's food industry, poultry is a prominent source of animal protein and accounts for more than 25% of local meat production [63]. In Australia, poultry meat is the most consumed with annual consumption of 46.2 kg per person [62]. In poultry and other birds, *E. coli* is a common member of the intestinal community [64]. Poultry meat undergoes rigorous and complex processing which results in higher levels of bacteria contamination compared with other meat types [62].

The diarrheal disease-causing *E. coli* strains are not frequently encountered in poultry meat. Despite this, human-like *E. coli* strains are thought to be harbored in poultry meat and may be a potential public health concern and zoonotic source of extra-intestinal pathogenic strains (ExPEC) [65] [66]. Over the years, antimicrobials have been incorporated into food animal production for disease prevention or treatment. However, antimicrobials use is gradually becoming a public health concern and few countries, like Australia, have placed a ban on the use of antimicrobials as growth promoters. Moreover, Australia has never approved the use of broad-spectrum antimicrobials like fluoroquinolones in food-producing animals [67]. Despite this, about two-thirds of the total antimicrobials' usage come from veterinary antimicrobials (including food-producing animals) in Australia.

The Prevalence of *Escherichia coli* in Free-Range

Fuh *et al.*, (2018) who examined the prevalence and antibiotic resistance of *E. coli* O157:H7 serotype from chicken droppings produced by free-ranged and confined birds. Six sampling areas were studied and free-ranged birds from sampling area 3 had the highest percentage prevalence of 11.67% while confined birds had 3.33%. Also, there was significant difference between the confined birds and free-range birds. For the confined birds, the highest prevalence percentage of *E. coli* OH157:H7 was among broilers (3.33%) 4 to 12 weeks old while the lowest value was among 1 to 6 weeks old (1.11%). On the other hand, free-range had the highest prevalence percentage among 1 to 3 weeks old (10.89) while 18 to 72 weeks old layers had the lowest (2.22%). The authors demonstrated that both the confined and free-range production systems harbor *E. coli* O157:H7 but free-range birds had the highest prevalence. They argued that the low prevalence among confined birds could be due to regular administration of antibiotics by which most poultry farmers tend to protect the birds against infection [38]. A similar result was also reported in poultry farms in Lagos and Ibadan, Nigeria [68]. Other authors reported that *E. coli* was the most prevalent bacteria (53.50%) in poultry droppings in Akure, Ondo State, Nigeria [69]. Another research conducted in Ethiopia revealed that out of 194 cloacae samples examined for *E. coli* O157:H7, 13.4% were found to be positive for *E. coli* O157:H7 [39]. Free-range chicks aged 1 to 3 weeks have the highest prevalence (10.89%) of *E. coli*. Another study buttressed the same point with a higher prevalence of 18.8% among young birds while the adult birds had 7.5%. It is inferred that the higher prevalence among chicks (1 - 3 weeks) may be a result of low immunity associated with young birds. Moreover, the authors argued that all the groups get their food from a common source and as such get exposed to the same environmental conditions [39]. Resistance to tetracycline, ampicillin, nitrofurantoin and chloramphenicol were observed when 9 isolates were screened against 11 commonly used veterinary antibiotics [38].

4. Intervention Strategies for Microbial Control on the Farm

4.1. Salmonella Control

Foodborne illness caused by *Salmonella* is a worldwide issue. Both pre-harvest and post-harvest methods are used to reduce *Salmonella* contamination of layer flocks. The pre-harvest methods employed are; 1) vaccination, 2) genetic lines of laying hens, 3) feed management practices, 4) flock management such as biosecurity, pest control, cleaning and disinfection, 5) natural antimicrobial products such as bacteriophage, competitive exclusion flora, probiotics, prebiotics and organic acid. Also, several post-harvest methods used are; a) biological methods such as plant extracts, b) physical methods such as irradiation, UV, microwave, pulsed light, gas plasma technology, c) egg storage at ambient temperature, and d) chemical methods such as; egg washing with sanitizers, electrolyzed water, ozone and hydrogen peroxide [70].

One important method of preventing *Salmonella* in poultry is vaccination. Currently, there are live and killed *Salmonella* vaccines [71]. Through spontaneous mutations or attenuation by chemical or ultraviolet mutagenesis, live vaccines are made [72]. As of now, some countries, such as Australia, have no recognised vaccination control program in layer flocks against *Salmonella* serovars that are relevant to human health. The variation between individual producers and across the states in vaccination activities exist [47] due to the uncertainty of long term efficacy of the currently available *S. typhimurium* vaccine in the field. Extensive egg washing is used in Australia, Canada, USA, and Japan to decrease eggshell contamination [70]. However, there is a debate on-going about the advantages of egg washing due to the risk of cuticle damage and the penetration of *Salmonella* from shell surface into egg contents. Report from previous studies indicated that egg washing may increase the likelihood of penetration of *S. typhimurium* through the eggshell, particularly during storage and drying conditions, if egg washing procedures are below standard [73].

Use of Organic Acids in *Salmonella* Control

Organic acids are popularly used in the poultry industry as feed and water additives to combat specific pathogens, including *Salmonella*. Poultry has data on the efficacy of organic acids that are potentially used as feed and water additives to control *Salmonella* contamination. *Salmonella* colonization in animal tissue and further transmission can be prevented by including organic acids in feed, drinking water and other matrices [74]. It is believed that the major source of *Salmonella* in layer farm environments is via contaminated poultry feed. Therefore, incorporating organic acids in poultry feed would decontaminate feed and reduce the ingestion of *Salmonella* by chickens. In a previous study, a commercial brand of formic acid was shown to significantly reduce the number of *Salmonella* positive feeder samples from 4.1% to 1.1% after the feed was treated with 0.5% formic acid [75].

Many studies have come up with a new range of products in which SCFA (Short Chain Fatty-acid) are encapsulated in mineral carriers resulting in slow release during the transport of these acid products through the intestinal tract. Studies have also shown the efficacy of acetic acid, formic acid or propionic acid on the colonization of *S. enteritidis* caeca, liver and spleen [76].

4.2. Campylobacter and *Escherichia coli* Control

In controlling *Campylobacter* and *E. coli*, the strategies need to be goal orientated. Three-tiered approach has been proposed by codex for this purpose. The first tier has to do with hygiene measures to be adopted followed by the hazard specific measures and lastly the risk-based measures. Preharvest and postharvest are the two intervention methods employed for bacterial control on farm.

4.2.1. Pre-Harvest Intervention

These methods are used to prevent colonization of poultry by bacteria on the farm. Studies have shown that poultry shows a lag phase of 2 - 3 weeks to *Campylobacter* colonization, but once a bird is colonized, the whole flock gets affected in few days as the organism can be transmitted through feco-oral transmission and via feed and water [77]. In order to avert colonization and consequent amplification, appropriate interventions would be necessary. Three general strategies employed to control *Campylobacter* and *E. coli* on poultry farm are; "1) reduction of the environmental exposure such as biosecurity measures, 2) an increase in the poultry's host resistance to reduce *Campylobacter* carriage in the gut such as competitive exclusion, vaccination and host genetics selection, and 3) reduction and elimination of *Campylobacter* and *E. coli* from colonized chickens through the use of antimicrobial alternatives" [78].

Phage therapy can be used to reduce the prevalence of *Campylobacter* in poultry. Bacteriophages are ubiquitous and naturally occurring predators of bacteria. Research has shown that there are *Campylobacter* specific bacteriophages that have been isolated from various sources like broiler chickens, and manure. Previous study has shown the application of bacteriophages as a decontamination technique to reduce the amount of *Campylobacter* entering the food chain at the farm level leading to a measurable reduction in carcass contamination [79].

4.2.2. Postharvest Intervention

Hauling and transportation can be a source of microbial contamination of food animals. During transportation and holding before slaughter, *Campylobacter* colonization increases due to defecation onto crates and birds in crates below [80]. Scheduled slaughter can be used to identify flocks positive for *Campylobacter* and *E.* coli and subject carcasses from these flocks to special treatment such as freezing, heat treatment immediately after slaughter. Another method is a logistic slaughter which prioritizes slaughtering positive flocks after negative flocks to avoid cross-contamination [21].

5. Conclusions

In any production system, management is the key to optimizing animal welfare and ensuring reduction in bacterial contamination. Although the free-range production system is becoming more popular, studies comparing the standard and free-range production systems are inconclusive and contradictory. One can assume that there is an increase in animal welfare based on the criteria for the free-range production system. However, there are also increased risk factors that can adversely affect bird welfare and product quality. These factors could include but not limited to greater difficulties maintaining hygienic standards, increased contact with infectious agents, increased possibilities of unbalanced diets and threats of predation.

When it comes to production systems, food safety is an important consideration, Figure 1 represents the common microbial contamination in free-range poultry production. The two main sources of poultry products contamination are *Salmonella* and *Campylobacter*. *Salmonella* transmission is the most significant health risk for eggs. In North America, *S. enteritidis* is the most prevalent while *S. typhimurium* is more common in Australia and New Zealand. Table 1 presents the prevalence of *Campylobacter*, *Salmonella* and *E. coli* in free-range poultry production systems in other selected countries. Comparing bacterial loads of poultry meat from conventional and free-range systems has been conflicting, however, some studies have shown increased bacterial loads in a free-range production system. Comparing research results between systems can be difficult due to differences in seasons, geographical location, and detection and isolation methods used.

Consumers can easily be influenced by media and free-range advocates because they perceive a free-range system to be animal friendly and safe. However, irrespective of research conclusion or public view regarding the relative food safety of chickens, consumers should be careful not to assume that all free-range chickens are free of *Salmonella*, *Campylobacter* and *E. coli.* Moreover, the same is applicable to conventional production systems. This review paper has

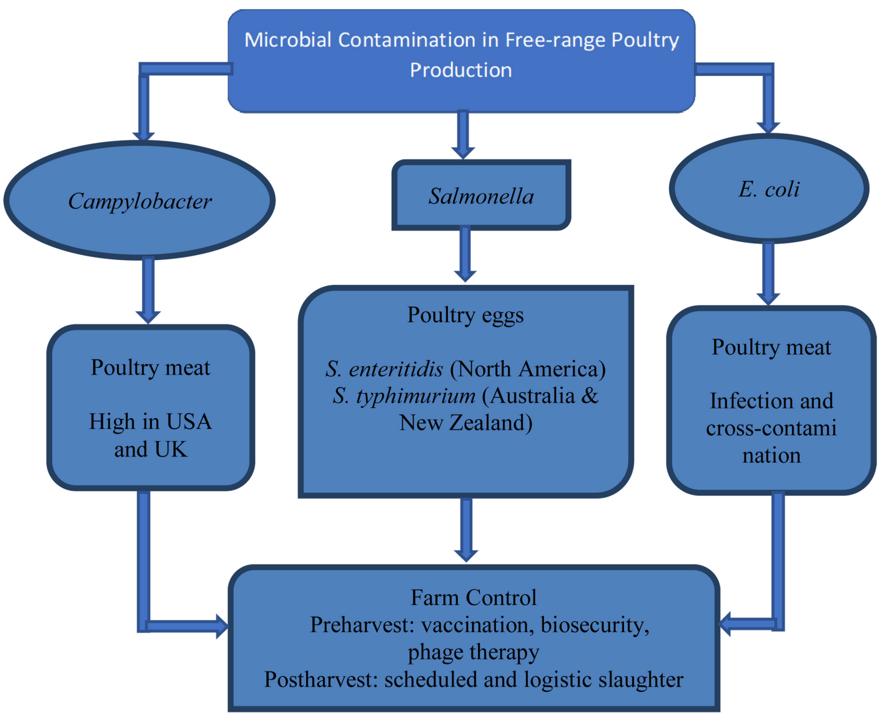

Figure 1. A graphical representation of the common microbial contamination and control in free-range poultry production.

Table 1. The prevalence of *campylobacter*, *salmonella* and *E. coli* in free-range poultry production systems in selected countries.

Microbial Contamination	Country	Sample size	Prevalence (%)	References
Campylobacter	Spain	34 farms	70.6	[26]
	USA	-	95-100	[28]
	Belgium	6 farms	100 (Summer) 66.7 (Spring) 33.3 (Winter)	[29]
	Greece	-	29.4	[30]
	UK	28 farms	95 - 100	[31]
	South Africa	-	47	[32]
	Ireland	510 raw chicken products	84.3	[33]
Salmonella	Italy	196 flocks	1	[34] [35]
	Netherlands	196 flocks	7	[34] [35]
	Spain	60 flocks	2.9	[26]
	Chile	50 carcasses	0	[27]
	USA	-	50 - 100	[28]
	China	300 fecal swabs	12.7	[36]
	Colombia	1003 broiler chickens	27	[37]
	Ireland	510 raw chicken products	5.1	[33]
Escherichia coli	Nigeria	6 study areas	11.67	[38]
	Ethiopia	194 cloacae swabs	13.4	[40]
	Cameroun	150 chickens	92.7	[41]
	New Caledonia	150 chickens	96.7	[41]

emphasized that proper handling of poultry meat, irrespective of the production system, is important and should be taken seriously. Microbial eggshell contamination in both cage and free-range nests is comparable from well-managed facilities. The difference is often observed from eggs that are laid on the floor and the range paddock, which have more microbial loads that cannot be decreased washing to a safe level. Another concern of the food safety of eggs from free-range is chemical safety because in some locations, dioxins, pesticides and lead are challenges associated with free-range.

There are several intervention strategies that are being used to combat the microbial contamination of poultry to ensure product quality and safety. Both pre-harvest and post-harvest methods are used to reduce microbial loads in poultry. However, it is important to note that there is variation in farming systems used in free-range poultry production such as housing and range availability, opportunities for pasture rotation and differences in farm size.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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