Chapter 11

Preharvest *Salmonella* Risk Contamination and the Control Strategies

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Additional information is available at the end of the chapter

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Abstract

Salmonella is present in most food production environments and can enter the food supply at any stage of food production from farm to fork. Control strategies for *Salmonella* include preharvest and postharvest aspects. Preharvest approach is very important because as a result of large-scale production, many animals could be infected with *Salmonella* serotypes during the primary production, causing human salmonellosis by consuming meat, milk, and eggs or foods containing ingredients of animal origin. The first step for prevention approaches is to determinate the source of infection; *Salmonella* serovars should be founded, and control strategies must be executed. Infection sources include vertical transmission, feed, pest (rodents and insects), wild birds, water, humans, manure, transportation coops, tractors or vehicles, and farm environment. Preventive and control strategies involve many factors, including hygiene, biosecurity procedures, animal feed surveillance, litter, manure and carcasses disposed, cleaning and disinfection programs, food interventions, diagnostic, and vaccination.

Keywords: *Salmonella*, preharvest, farm to fork approach, surveillance, sources of infection, biosecurity, feedstuffs, cleaning and disinfection, pest control, water safety, vaccination, litter and carcasses disposal

1. Introduction

Salmonellosis is one of the most common food-borne bacterial diseases in the world. In most food animal species, *Salmonella* can establish a clinically unapparent infection of variable duration, which is significant as a potential zoonosis.

Human food-borne salmonellosis has increased in association with the development of food industry. Food industry is based on large-scale animal production. Food processing plants have grown larger, and when there is a salmonellosis outbreak, it will infect many more people than in the past. In addition, there has been a change in dining habits of consumers, and a high proportion of meals are eaten at institutions, restaurants, and fast food places. These establishments are often a significant link and amplifier of *Salmonella* infections.

Salmonella is present in most food production environments and can enter the food supply at any stage of food production from *farm to fork*. Control strategies for *Salmonella* include preharvest and postharvest aspects. Most control strategies for *Salmonella* are focused on specific aspects of food production or processing and are generally assessed on their ability to reduce levels of *Salmonella* spp. at the processing stage.

Nevertheless, preharvest approach is very important because as a result of large-scale production, many animals are placed in small area producing a lot of feces. Several *Salmonella* serovars that are not host specific may colonize the digestive tract of animals, provoking human salmonellosis by consuming meat, milk, and egg or food containing ingredients of animal origin.

Animal feed (and ingredients therein) has been described as a source of *Salmonella* infection for animals and humans, through the contamination of food products of animal origin. This threat is aggravated due to the bacteria capability to persist for long periods in a wide variety of feedstuffs. Therefore, animal feed may serve as vehicle to introduce *Salmonella* serovars into the food chain and could contribute to the circulation and spreading of antimicrobial-resistant bacteria or antimicrobial-resistant genes.

At the farm, level food safety programs involve many factors such as hygiene, biosecurity procedures, animal feed surveillance, litter and carcasses disposal, depopulation, cleaning, disinfection programs, food interventions, diagnostic, and vaccination. The source of infection should be determined. At the end of the production, animals should be sent to slaughter with special precaution, and they should be healthy to prevent contamination during the processing.

Other strategies should be taken during the transport and time of slaughter to decrease *Salmonella* contamination. A good food safety program should include the entire food chain of production; however, the aim of this chapter is to describe preharvest *Salmonella* risk contamination factors including *Salmonella* prevalence in animal feedstuffs and the control strategies and interventions.

1.1. Farm-to-fork concept

"Farm to fork" is a strategy to prevent food-borne hazards. This approach is based in many measures to trace the different stages of the food chain. "Farm-to-fork" system examines the practices and procedures that ensure food safety.

The procedures to prevent *Salmonella* contamination in the food chain comprise many events, from the primary production to the final consumer. *Salmonella* contamination events can occur during different parts of the food chain which included primary production, processing, distribution, preparation, and dining habits of consumers.

In 2003, Food and Agriculture Organization (FAO) of the United Nations [1] showed the importance about a new approach in food-borne hazards which it had called "food chain approach." Its objective is to ensure that the food is free from borne hazards: pesticides, chemicals, bacteria, and others contaminants. Every food chain step has to be analyzed: growing, raising, production, collecting, processing, packing, commercialization, and consumption.

The FAO and World Health Organization (WHO) [2] have produced guidance documents for use by governmental authorities on food-borne outbreak investigation [3]. They suggest that good control measurements at the farm level are likely to correspond with lower prevalence of *Salmonella* infection and, subsequently, a reduction of cross contamination of carcasses processed at the slaughterhouse and a reduction in human salmonellosis.

1.2. One health

Also, Codex Alimentarius (CA) standards and risk analysis methodologies are recognized in the area for food safety. The CA and the World Organization for Animal Health (OIE) are working together to develop their respective standards for food-borne zoonosis so that they are non-duplicative, cohesive, and will cover the whole food chain [3].

Primary production is focused in animal health, livestock, housing management, animal food quality, animal welfare, and transportation regarding for food processing.

Farming practices or primary production vary widely according to soil and climatic conditions, social conditions, cost of the feedstuffs, potential marketability of specific farm products, and the economic objectives of the farmer. However, there are general control strategies to prevent the entrance of *Salmonella* in primary production.

In spite of those production measurements, bacteria can enter anywhere in the food chain, causing animal disease and food contamination. One of the major sources of *Salmonella* in the food chain has been animal feed, especially swine and poultry. It is a major cause of economic loss in swine production [4] and has a great economic significance to the poultry industry around the world.

Salmonella could be a risk to public health through consumption of contaminated eggs and meat. These bacteria causes diarrheal diseases in humans [5] and high mortality in animals, like chickens. Other farm animals as cattle and sheep suffer disease, could become *Salmonella* reservoirs, and contribute as vector in the transmission.

2. Sources of infection

Salmonella genus is a group of microorganisms that are successfully adapted to live in very different environmental conditions [6]. For this reason, it is easy to find many potential sources of contamination, and control could be complicated. These sources include vertical transmission, feed, pest (rodents and insects), wild birds, water, humans, manure, transportation coops, tractors or vehicles, and farm environment. There are also some variables that contribute *Salmonella* contamination, such as age of the animal, survival of the bacteria through the gastric barrier,

competing bacteria in the intestinal tract, availability of a hospitable colonization site, the diet, physiological status, health, disease, and medications [7].

Identifying animal sources of infection, target interventions, and control measurements is the correct approach for preventing *Salmonella*; every source should be considered. Risk assessment studies have recommended an intervention for a productive overall approach.

2.1. Transmission

Salmonella is extremely widespread and very persistent in the environment. It is recovered from many vertebrates which included many farm animal species. Serovars of *Salmonella enterica* have varied hosts and reservoirs, cause disease in animals and humans, and can move between host species [5] because most of them are nonhost specific (**Table 1**).

Farm animal	*S. enterica* subsp. *enterica* serovar	Clinical signs	Authors
Sheep	Brandenburg Abortusovis Dublin Arizonae Typhimurium	Adults: abortion, gastroenteritis, pneumonia Lams: gastroenteritis, pneumonia, polyarthritis	[59]
Cattle	Dublin Typhimurium Montevideo Brandenburg Enteritidis Panamá Heidelberg Kentucky	Frequently is a subclinical disease Adults: diarrhea, enteritis abortion, depressed milk yield Calves: enteritis, arthritis, meningoencephalitis, respiratory signs	[59] [60] [61]
Poultry	Enteritidis, Typhimurium Paratyphi B Heidelberg Kentucky Infantis Gallinarum, pullorum	Frequently is a subclinical disease Gallinarum and pullorum (nonmotile): septicemia Others strains: asymptomatic	[62] [63]
Pig	Typhimurium Choleraesuis Derby Enteritidis Istanbul Mbandaka Agona Heidelberg	Septicemia and enterocolitis, pigs 6–8 weeks	[10] [26] [59] [64]
Horse	Typhimurium Newport Enteritidis St Paul Agona Anatum Heidelberg	Abortion, diarrhea, typhlitis, colitis, arthritis, nosocomial infections	[19] [64]

Table 1. *Salmonella enterica* subsp. *enterica* common serovars in farm animals.

In farm animals *Salmonella* cause clinical disease, and there are also asymptomatic animals called carriers, e.g., *Salmonella* subclinical infections persist in hens more than 22 weeks [8]. Carrier pigs are important as the initial source of contamination of the environment, other animals, and carcasses in the harvest [9]. Monitoring programs in the USA suggest that 20% of broiler chickens are contaminated with harmful *Salmonella* strains [6] and 27% incidence was found in feces in organic pig farms [10]. They are very important in the transmission because they can shed *Salmonella* in feces continuously and intermittently in the absence of clinical signs. Pets such as dogs and cats [11] show asymptomatic infections and could shed *Salmonella* and contaminated food-producing animals.

There is a different *Salmonella* susceptibility in farm animals. Stressors can aggravate *Salmonella* shedding, including mixing, climate, transportation, and food deprivation. Some results suggest that the duration of *Salmonella* shedding might depend on serotypes, strain, animal age, farm, or others risk factors [10].

Horizontal transmission also occurs by fecal-oral route or by aerogenous transmission. In pigs oropharyngeal secretions can contaminate and spread the disease via nose to nose [12]. *Salmonella* can be introduced in a herd through new purchased and infected pigs. There is evidence of bacterial spread by feed, drinking water, fomites, asymptomatic carriers, and dry feces from infected animals with clinical disease.

Vertical transmission is crucial in poultry related infected with *S. enterica* subspecies *enterica* serovars Enteritidis, Typhimurium, Gallinarum, Heidelberg, and Infantis [13]. *Salmonella* produces persistent infection in birds, located in the ovary [13]. Transmission to progeny occurs by transovarian infection, when the ovary and the developing eggs became infected in the oviduct. Bacteria migrate inside the yolk before shell deposition. *Salmonella* enteritidis can also get access to eggs by migrating from the cloaca to the reproductive organs. *S. enterica* subsp. *enterica* serovar Heidelberg was the most common serovar founded in ovaries in layers in Canada [8]; there is evidence supporting vertical transmission of *Salmonella* in dairy cattle [14]. *Salmonella* might be transmitted vertically from the dam to her fetus in utero. Calves might be infected with *Salmonella* at birth or post birth.

If progeny persists infected, there is no chance of eradication, and the control becomes complicated. From a public health point of view, the number of eggs and animals affected by *Salmonella* is a risk for a human disease or infection.

2.2. Feed

Animal feed is a recognized source of *Salmonella* for farm livestock. Bacteria can be introduced into the feed by contaminated feedstuffs, processing, transport, storage, distribution, and administration due to dirty feeders.

Salmonella can be isolated frequently from animal-feed ingredients, such as meat bone meals and fish meals. Few quantities of *Salmonella* cause infection, less than one *Salmonella* per gram of feed has been shown to establish colonization in 1- to 7-day-old chicks [15].

Salmonella could be isolated from feedstuff in 17.6% of pig herds among five EU countries and from 6.9% of all feed samples [16], and also it can survive at least 26 months in artificially contaminated poultry food [17].

2.3. Farm environment

Farm *Salmonella* eradication is a complicated strategy, and its control could be difficult because there are numerous potential source environment. It is able to grow between 7 and 45°C, is destroyed at 65°C during 10–15 minutes, and resists every acid pH and salt added in food up to 20% [6].

Animals are the major reservoir of *Salmonella*; dissemination into environment has resulted from the human practices and animal behavior. *Salmonella* may be present in any waste from human or animal activities; it survives in frozen food and remains viable during years in the environment. In broiler houses, microorganisms could persist for at least 1 year [18]. *Salmonella* is shed efficiently in feces, persists within the environment, and is spread readily between food-producing animals in the farm environment. *Salmonella* can survive desiccation and persist for many months in association with dust particles on fans, floors, and feed deposits.

This microorganism can survive and replicate for long periods in different environments, although the original fecal source may be remote in time. For instance, *S. enterica* subsp. *enterica* serovar Choleraesuis persists in dry feces 13 months post shedding and after disinfection process and survives in soil between 25 and 200 days [5].

Bailey et al. [7] found that the environment was the primary source of contaminating *Salmonella* in chicken houses not treated with competitive exclusion microflora. They recovered high rates of *Salmonella* from feces, litter, and near the entrance doors to the poultry houses. Hatchery transport paper pads were the most frequently observed *Salmonella* positive in this research. Salmonellosis is also commonly observed in contaminated facilities in veterinary hospitals [19]. Barns, pens, dust, egg belts, feeders, fans, feed bins, vehicles, and equipment can be contaminated.

Survival capacity, environment persistence, and infection may be influenced by different genetic, productive, and environmental factors such as intensification of handling practices, reduction in genetic diversity of breeding stock, and increasing standardization of food types [5].There is a differential distribution of specific serovars and genotypes between animals and environments. Certain serovars have a greater ability to establish infection, shedding patterns, and concentration. In pigs, *S. enterica* subsp. *enterica* serovar Typhimurium was more frequently isolated from the manure compared to other bacteria [20].

2.4. Water

Contaminated water supplies have been implicated in the introduction and persistence of *Salmonella*. Contaminated waters might contribute through direct ingestion of the water or via indirect contamination of the surfaces. In a review [21], they found *Salmonella* in different

countries and in very diverse water sources. *Salmonella* contamination occurred in surface water used for recreational purposes, as source of drinking water and for irrigation. They detected a mixed of human and animal origin of *Salmonella* serovars in drinking water sources.

In artificial freshwater systems, *Salmonella* and *Escherichia coli* survived for at least 56 days [5]. Factor contributes to *Salmonella* resistance, and persistence in water is its capacity to attach to different types of plastic, glass, cement, rubber, and stainless steel or biotic surfaces (plant surfaces, epithelial cells, and gallstones) [6]. *Salmonella* forms a complex called biofilm inside drinkers and pipes. This biofilm is a bacteria surface-associated formation that allows bacteria to resist against different stress factors such as desiccation, disinfectants, and antibiotics [22].

2.5. Pest

2.5.1. Rodents

Mice and rats are involved in the transmission and the perpetuation of the infection in the farm buildings and facilities. Rodents can be long-term sources of *Salmonella* infection. Their droppings can be contaminated for up to 3 months for infection. A study found that 3 weeks old chicks became infected via mice artificially contaminated with *S. enterica subsp. enterica* serovar Enteritidis 5 months before [23].

Mice travel from one farm to another; they leave empty farms or facilities and return after cleaning and disinfection activities. They have also good reproductive capacity and can spread *Salmonella* for one flock to other flocks or herds. They contribute to perpetuate infections. Rodents are important vectors and amplifiers of *Salmonella* infection in farm animals, e.g., mouse fecal pellets have been shown to contain up to 10^4 CFU of *Salmonella* [23, 24]. One single mouse can shed 100 fecal pellets per day [24]. Fecal pellets are seed shaped; pigs and chicken eat these pellets and become infected. On a clean pig farm, 5–10% rodents can be found infected with *Salmonella* [25, 26]. Isolates from contaminated mice contained three times more *Salmonella* than isolates from environment of contaminated house samples [24]. The presence of a mouse-infected population is an important risk for animal and product contamination. Layer farms with high rodent densities showed more *S. enterica* subsp. *enterica* serovar Enteritidis and serovar Infantis isolations and hens infected than farms with low rodent densities [27].

Rats, mice, and cats are associated with contamination of water, food, and grains stored. They carry bacteria in their intestinal tracts without clinical symptoms and disease and cause transmission of pathogens to farm animal feed and environment. Rodents acquire the infection from feces of sick animals, wild animals, and members of their family [23]; they also get infected from outdoor paddocks and inaccessible feces-contaminated parts of the livestock houses.

The environment conditions around facilities attract rodent, e.g., waste, spilled food and feedstuffs, sources of water, and abilities to build dens. Dead mice also can be a contamination source if they remain in the barns of houses after cleaning and disinfection procedures.

2.5.2. Darkling beetles, flies, mites, ticks, and cockroaches

Salmonella is widely distributed in flies and less in beetle and mites of affected livestock units. Farms offer great and suitable niches as manure, dust, spilled food, and long production periods of time without cleaning.

Flies act as mechanical vector; the *Musca domestica* is most prevalent in farms and associates with zoonosis. They perform diurnal excursions around animal houses and can fly many miles from the farms contributing with *Salmonella* dissemination. Heavy fly populations have been identified as a risk factor for *Salmonella* in poultry, dairy cattle, swine, and feedlot cattle [28]. Authors report that flies carry *S. enterica* subsp. *enterica* serovar Typhimurium for up to 10 days [26]. Flies become contaminated from environment, and animals ingesting contaminated flies get infected. There is not enough evidence of flies as biological vector (*Salmonella* multiplication inside the flies).

Darkling beetle *Alphitobius diaperinus* is a very common pest in poultry houses. They carry and shed by defecation variety of microorganisms which included *Salmonella*. Beetles survive cleaning and disinfection because they hide in inaccessible poultry house structures and outside of the poultry buildings. They drill wall cavities complicating insecticides access. Chickens can ingest contaminated beetle larvae and adults and become infected. *Salmonella* isolates from beetles are usually lower than isolates from flies [29].

Mites can acquire and transmit *Salmonella*. The most frequently mites founded in poultry are *Dermanyssus gallinae* (red mite), *Ornithonyssus sylviarum*, and *Ornithonyssus bursa.* They are usually present in manure, litter, and feed. Adults and nymphs of ticks visit poultry houses only to feed; adults can survive for months or years at swine or poultry facilities. A *Salmonella* vector role for ticks remains speculative.

Cockroaches will opportunistically colonize animal facilities and carry bacteria. They have been reported to carry *Salmonella* [30] and can transmit these bacteria to other cockroaches and to eggshells.

2.6. Wild animals

Wild bird and little mammals are regarded as the main reservoir for *Salmonella* in the environment. Wildlife vectors may be responsible for the introduction of some Salmonellae to farms.

Birds as pigeons, sparrows [5], foxes [31], shrews, reptiles, and other wild animals have a potential role in the *Salmonella* dissemination [29]. The spread or recycling of *Salmonella* infection among livestock may occur through the contamination of water or feed or the direct contamination of the environment. Building, houses, and barns should be constructed to block wild animal access. Birds cannot nest and reproduce in the houses to prevent bacterial contamination.

2.7. Humans

Human traffic on the farm increases the risk of infection in pigs, chickens, and hens. The entrance of visitors was associated with higher *Salmonella* prevalence [32].

People transport pathogens from their nose, hair, throat, pharynx, clothes, and shoes. They also could have *Salmonella* in their intestine; therefore, having access to toilets and washing facilities have a protective effect against *Salmonella* [9].

3. Surveillance and prevalence of *Salmonella* in animal feedstuffs

Animal feedstuff could serve as vehicle for *Salmonella* serovars into the farm environment and cause animal infection that could reach the human consumer through animal food products. As we already mentioned above, *Salmonella* has the capability to survive in a vast variety of commodities and to resist desiccation among other adverse conditions. During our work and research in *Salmonella* surveillance in animal feed, we have seen that *Salmonella* has the ability to remain in different animal feedstuffs for long time periods; this has been also confirmed by other research groups [33, 34].

Animal feedstuffs have been found to be a cause of *Salmonella* infection in animals and humans [17, 35, 36]. In spite of this, there is controversy in the roll or relevance of animal feed in food-borne infections since the serovars frequently isolated from animal feed do not correlate with the serovars frequently associated with human infections. Through animal feed new *Salmonella* serovars and resistance bacteria could enter and spread into the food chain [37, 38]. The surveillance and control of *Salmonella* in animal feed and feed ingredients should be an important part of animals and food safety programs aimed to counteract *Salmonella* food-borne infections.

In many countries around the world, *Salmonella* surveillance feedstuff programs are being executed; each program has its own specific objectives and specifications. For example, in Costa Rica all finished feed and feed ingredients must be registered and inspected by the Ministry of Agriculture and Livestock. These feedstuffs are also analyzed for *Salmonella*, and this must be absent regardless the serovar. In contrast with the FDA guidance for control of *Salmonella* in food for animals, the FDA recommended regulatory actions depending on the serovar found and the animal species that would receive the feed [39]. The serovars that have been reported to cause disease in the animal species for which the feed is for should be absent, for example [39]:

Poultry feed: *S. enterica* subsp. *enterica* serovar Gallinarum and Enteritidis

Swine feed: *S. enterica* subsp. *enterica* serovar Choleraesuis

Sheep feed: *S. enterica* subsp. *enterica* serovar Abortusovis

Horse feed: *S. enterica* subsp. *enterica* serovar Abortusequi

Dairy and beef feed: *S. enterica* subsp. *enterica* serovar Newport or Dublin

These differences between the *Salmonella* control programs could hamper international trade. Furthermore, in a previous research [40] in which we analyzed 1725 samples of feed and feed ingredient between the years 2009 and 2014, we found *Salmonella* serovars which do not frequently cause disease in animals but have been involved in food-borne outbreaks.

In our study, the overall *Salmonella* prevalence in animal feedstuff was 6.4%. Finished feeds such as: poultry, pet, and swine and feed ingredients such as: meat and bone meal (MBM), fish meal and poultry meal were tested.

Meat and bone meal and poultry feed presented the higher *Salmonella* relative prevalence 26,7 and 5,4%, respectively [40]. **Figure 1** shows the most frequently found serovars in MBM and poultry feed in this study [40, 41]: in MBM: *S. enterica* subsp. *enterica* serovar Give (13.8%) and serovar Rissen (4.6%) and in poultry feed: *S. enterica* subsp. *enterica* serovar Havana (10.8%), serovar Rissen, serovar Soerenga, and serovar Schwarzengrund (6.2%). These serovars have been associated with animal and human infections and outbreaks [42–44].

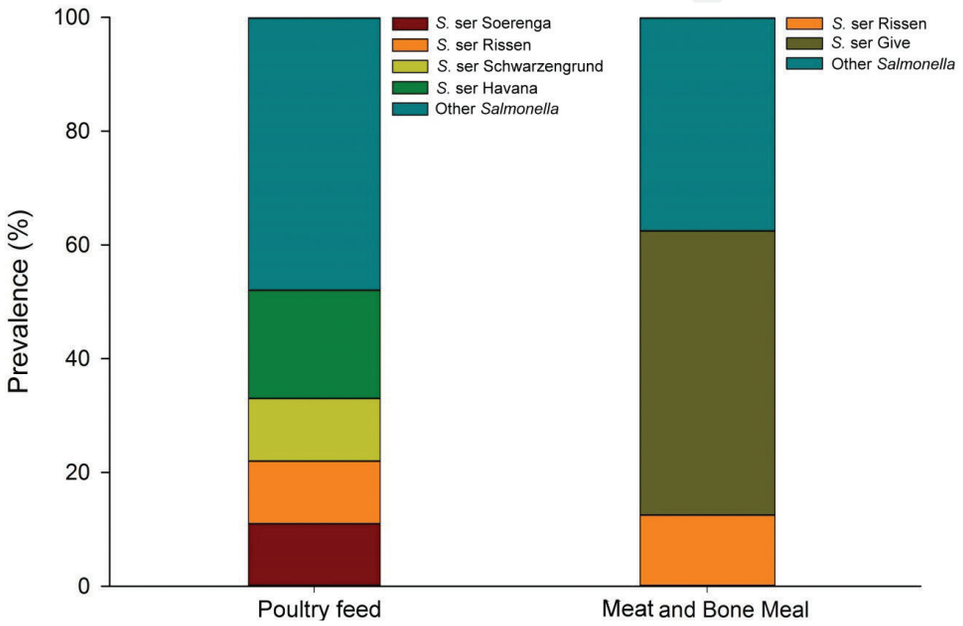

Figure 1. Distribution of *Salmonella enterica* serovars among the isolates found in feed and feed ingredients in Costa Rica [41].

The high *Salmonella* prevalence found in MBM in our previous study [40] is worrying given that MBM is used in some countries as a relative cheap protein source to feed pets and monogastric animals [38, 45].

In the EU, there is also no common sampling plan for *Salmonella* surveillance in animal feed; in the EFSA report for 2014, the overall level of *Salmonella* contamination in feedstuff was 3.8% [46] similar to our previously reported prevalence for Costa Rica [40].

4. Detection and surveillance of *Salmonella* in food production systems

Owing to the fact that *Salmonella* is ubiquitous and has the capability to survive in a great variety of commodities, it is important to control it in each step of the food chain in order to minimize the risk of human infections and food-borne outbreaks and achieve safer food to consumers. It is crucial to maintain a *Salmonella* surveillance program in food-producing animals

in order to reduce food-borne Salmonellosis and infections in animals causing economic loss to the livestock sector. The fact that *Salmonella* in animals causes frequently subclinical infections that could go unnoticed favors the *Salmonella* spread in a herd or flock [47].

Table 2 shows the *Salmonella* prevalence in farm animals, and the serovars most commonly found in animals and in their meat according to the last EFSA and ECDC [46] report. In this report, the authors demonstrated that the most prevalent serovars were shared between food producing animals and the meat for consumption. In contrast, other researchers (including ourselves) found no relation among the strains encountered in feed, live animals and processed meat [40].

Farm animal	Overall EU prevalence of *Salmonella* (2014)	Most commonly serovars in flock	Most commonly serovars in meat
Breeding and fattening turkey flocks	3.3%	*S. enterica* subsp. *enterica* ser. Infantis (22.2% of isolates)	*S. enterica* subsp. *enterica* ser. Stanley, *S. enterica* subsp. *enterica* ser. Infantis, and *S. enterica* subsp. *enterica* ser. Typhimurium
Breeding and fattening pigs	7.9%	*S. enterica* subsp. *enterica* ser. Typhimurium (54.7%) and *S. enterica* subsp. *enterica* ser. Derby (17.5%) (of 2037 isolates)	*S. enterica* subsp. *enterica* ser. Typhimurium (27.8%), *S. enterica* subsp. *enterica* ser. Derby (24.4%), and monophasic strains of *S. enterica* subsp. *enterica* ser. Typhimurium (18%)
Cattle (breeding animals, dairy cows or calves, or were unspecified)	3.9%	*S. enterica* subsp. *enterica* ser. Typhimurium (46.8%), *S. enterica* subsp. *enterica* ser. Dublin (31.3%), and *S. enterica* subsp. *enterica* ser. Enteritidis (4.6%) (of 3243 reported isolates)	*S. enterica* subsp. *enterica* ser. Derby (24.7%), *S. enterica* subsp. *enterica* ser. Typhimurium (20.6%) and *S. enterica* subsp. *enterica* ser. Enteritidis (17.8%)

Table 2. *Salmonella* prevalence in farm animals and their meat in the Europe Union [46].

5. Control measures for *Salmonella* in food production

The objective of preharvest approach is to minimize opportunities for the introduction, persistence, and transmission of *Salmonella* infections and other animal pathogens. Strategies should be directed against all *Salmonella* serovars, but sometimes more specific strategies against particular *Salmonella* serovars are required when one of them has high public health impact or economic significance.

Most of the time, general strategies are sufficient to control all *Salmonella* serovars; nevertheless, sometimes it is necessary to apply specific tools, e.g., vaccination against specific serovars. Prevention programs or strategies included risk reduction, risk management, and verification by implementation of biosecurity programs.

Biosecurity is known as a group of procedures or prevention measurements to protect farm animals against biological agents, such as bacteria, viruses, fungi, parasites, protozoa, and any

other agents able to induce infectious diseases into a farm. Biosecurity programs identify risk, origin, reservoirs, vector, and carriers, preventing the access to the farm. It includes strategies as control of wild birds and flies, obligatory disinfection of boots, clothes, and equipment for farm workers and visitors. Cleaning and disinfection of houses, litter, and dead animal's management and vaccination are also important in a prevention program.

5.1. Cleaning and disinfection

High level of *Salmonella* persisting for months in surfaces and contaminated facilities demonstrates the importance of cleaning organic matter and dust from the environment and animal houses. Empty houses should be cleaned and disinfected between flocks and herds.

Cleaning has to be detailed, using water and appropriate detergents. In poultry houses, cleaning should be focused in difficult access places as ceilings, cages, egg-conveyor belts, egg-grading equipment, manure belts, feed troughs, hoppers, feed bins, louvers, curtains, brush blades, air inlets, fans, and other ventilation equipment. Feather removal is an important measure in poultry facilities. Also, frequently visited rooms should be cleaned; anterooms, egg-packing rooms, and egg-storage rooms, offices, storage rooms, and restrooms can be contaminated.

After washing and cleaning, administration of disinfectants by high-pressure spray, foam, and fumigation reduce environmental contamination. Disinfectant dilutions and application directions should be strictly followed. A suitable disinfectant against *Salmonella* should have residual properties and activity in the presence of organic matter. Drying of houses immediately after application of disinfectants is highly advisable to reduce water activity, which allows *Salmonella* multiplication.

Disinfectants as sodium hypochlorite or quaternary ammonium compounds are able to eliminate *Salmonella* bacteria. Other studies showed that the use of glutaraldehyde, formaldehyde, and peroxygen at a concentration of 1% in field conditions was inadequate for the elimination of *Salmonella* in the farm [48]. Higher doses should be used. Povidone-iodine, potassium permanganate, ethanol, chlorhexidine digluconate, and hydrogen peroxide exhibited high efficacy in other studies [49, 50].

Recontamination after cleaning and disinfecting may occur. Houses recently cleaned should be closed before animals arrive to prevent organic matter and dust contamination. Equipment should be washed and disinfected before entering a house to prevent recontamination.

5.2. Vaccination

Vaccination is a specific control tool against *Salmonella*. Vaccines are used to increase the infection resistance. It can enhance the short-term responsiveness of control programs but does not completely eliminate problems. A combination of biosecurity procedures, *Salmonella*-free replacement of flocks and herds, and vaccination should be a suitable control approach. Farm management programs need integrated interventions to be satisfactory.

Immunization has been shown to significantly reduce the number of hens infected by *S. enterica* subsp. *enterica* serovar Enteritidis and the rate of egg transmission [51]. Live-attenuated vaccines and nonliving vaccines (bacterins) of *S. enterica* subsp. *enterica* serovar Enteritidis vaccines are used to immunize chickens. Live vaccines are used against *S. enterica* subsp. *enterica* serovar Gallinarum and Typhimurium.

Live vaccines reduce intestinal and internal organ (spleen, liver, ovary, and oviducts) infection and stimulate mucosal immunity in the digestive tract [52]. Bacterins (killed vaccines) induce high levels of circulation antibodies and reduce colonization of internal organs and the number of bacteria in egg content [53]. However, they have a limited effect in feces shedding; for this reason, they may not contribute to prevent environment contamination. Therefore, a combination of both lives and bacterins are commonly used in layers and showed to be effective in *Salmonella* control in poultry [51].

Vaccination of sows and piglets can be helpful. Both vaccines are used, live and bacterins. Live vaccines are considered to provide good protection in pigs. However, some live vaccines in pigs show risks as reversion to virulence and excretion to the environment. And also, there is no differentiation between naturally infected and vaccinated animals [12]. Inactivated vaccines in sows could reduce transmission to the progeny and enhance maternal immunity. An effective, safe, and efficient vaccine program should prevent clinical symptoms, colonization, and development of carriers and reduce shedding.

5.3. Pest control

5.3.1. Rodents

Reduction or elimination of these vectors is an important part of the prevention strategies or control. An effective control program should be keep rodents number to the lowest level possible.

Chemicals and baits are the most common methods of rodent control. Farmers use frequently traps and cats. The use of cats as exterminator is not recommended. A study in a pig farm founded 12% of farm cat *Salmonella* [20] and *Toxoplasma gondii* positive [25].

A rodent control should have an integral approach, and it should include:

- Monitoring of rodent populations by visualization, traps, and creation of an index.
- Removal of old stored material and waste.
- Repairing facility structure.
- Do not allow rodents to enter the houses (repair holes, door seals, etc.).
- Removal of habitat elements and shelters for rodents near animal buildings, barns, and stables.
- Limiting access to water and feed.
- Limit the development of high rodent densities.

- Cleaning of outdoor paddocks.
- Removal of vegetation around the houses.
- The use of effective rodenticides.
- Secure disposal of died animals, litter, and waste.
- Do not maintain spilled feed.
- Follow strict biosecurity procedures.

It has been demonstrated that rodent integral control programs that follow these guidelines, has effectively decreased *Salmonella* in livestock animal houses.

Sometimes when high rodent densities are found, a program such as the mentioned is required.

5.3.2. Insects

For a successful insect control is required to keep litter dry and well ventilated, preventing wet areas and leaks is a must. Frequent removal of litter and replacement of fresh shavings in poultry houses can help to reduce beetle populations [54].

The use of insecticides such as :pyrethrins, carbamates and phosphates is a common practice. Sometimes, mite control could be complicated, because of the resistance from the insects to the acaricide; and also technical limitations like the usage in the lay period in hens. Rotation of insecticides reduces development of resistance.

Biological control methods should be used especially in animal production periods. Fly parasites, depredators, and insect growth regulators could be good options. Wettable powders are used with chemical insecticides in the beetle control.

5.4. Water safety

Water sanitation at the farm is essential in a biosecurity program. Drinking water sanitation can prevent initial contamination and recontamination of animals with *Salmonella.* Water filtration is a critical component of a water sanitation program. Dirty water cannot be effectively sanitized. Frequent washed and cleaned tanks are also required.

Chlorine is the most common disinfectant used in drinking water. It is a strong oxidizing agent and used to sanitize drinking water in farms. It is effective against Gram-positive and Gram-negative bacteria, viruses, fungal, and protozoa. When added to the water, a chemical reaction occurs, formation of Hypochlorous acid (HOCL) (weak acid) and Hypochlorite ion (OCL^-). Both are referred as free chlorine or available free chlorine. HOCL is more efficient as sanitizer. HOCL is necessary to keep low water pH, under 6.5 [55]. Chlorine is available in liquid form as sodium hypochlorite and in solid form as calcium hypochlorite. Sodium hypochlorite is usually available at a concentration of 10–12%.

Other halogens as iodine and bromine are used. Hydrogen peroxide, peracetic acid, ozone, and ultraviolet light showed to be successful to sanitize drinking water. Addition of organic acids to the drinking water showed variable results [56]. The antibacterial effects of acids depend on the type of organic acid, the bacterial species, the concentration used, and the physical form in which it is administered to the animals.

Strategies to reduce drinkers and pipe biofilm should be implemented. Biofilm causes resistance to free chlorine residuals, which can lead to persistence of bacteria in chlorine-treated water. Surfactin, glucose, halogenated furanones, 4(5)-aryl 2-aminoimidazoles, furocoumarins, and salicylates are used as biofilm inhibitors and disinfectant combinations of triclosan and quaternary ammonium salts or halogenated furanones and treatment antibiotics/disinfectants and microemulsions such as soybean oil in water [6]. It is essential that the effectiveness of sanitization program can be monitored.

5.5. Litter and carcasses disposed

Manure is one of the most important sources of *Salmonella* contamination. Pig slurry and poultry litter should not be spread, sprayed, or reused before a disinfection treatment. Land spreading of manure can lead to contamination of soil and water, which can potentially lead to bacteria transmission to animals and humans.

Transportation and disposal of slurry and manure from pig and poultry houses and barns, the transportation of slaughter offal to rendering plants, the cross contamination of rendered meat meal, and other poultry and animal byproducts contribute to spreading *Salmonella* in the environment [5].

If *Salmonella* is present in the litter and manure, the birds and pigs could be exposed at a time when they are highly susceptible and get sick. Well-designed facilities should avoid contact between animals and their feces. There are many manure treatments or disinfection procedures. Manure methods can be physical, chemical, biological, or a combination of all three and include technologies such as anaerobic digestion, composting, and separation. It has been shown that stored separate pig manure fractions under controlled conditions (10.5°C for 84–112 days) reduced *Salmonella* [57].

Salmonella may also be introduced into soil and the adjacent environment by decomposition of infected carcasses [5]. Dead animals should be disposed into a secured container, which is regularly washed and disinfected. Burying, composting, incineration, and dropping off at designated sites are the most commonly recommended and utilized methods for carcass disposed [58].

5.6. Transportation

Pigs and chickens and other animals increased shedding of *Salmonella* during transport from the farm to the slaughterhouse. Long transportation duration, high stock density, weather conditions, and long feed withdrawal are causes of bacteria increase shedding.

Feed tracks can also act as mechanical vectors and can transfer bacteria from one farm to another. Pig and poultry vehicles and drivers represent a considerable risk; therefore, they

should not be allowed into the clean areas of the farm. Transport vehicles, feed trucks, and chicken coops should to be cleaned and appropriately disinfected to prevent *Salmonella* contamination in harvest. In layers decontaminated and sanitized coops or cages and vehicles should be used to transport pullets from grow-out houses to the layer farm.

5.7. Feed additives and heat treatment

Organic acids and their salts, essential oils, formaldehyde, bacteriophages, probiotics, prebiotics, and symbiotics can be used to modify the gut environment to prevent *Salmonella* colonization, invasion, multiplication, and shedding. Probiotics consist of single or multiple beneficial bacteria strains that colonize intestinal tract; they compete with pathological bacteria as *Salmonella* for attachment sites, nutrients in the luminal surface of enterocytes. Probiotics also produce antibacterial compounds as bacteriocins and volatile fatty acids. Prebiotics are food ingredients as oligosaccharides that stimulate intestinal bacteria and probiotic growth. Symbiotics are products that contain both prebiotics and probiotics. Bacteriophages are viruses that infect and replicate in bacteria and have an effect against *Salmonella*.

Organic acids reduce *Salmonella* in contaminated feed. Formic and propionic acids and their salts are commonly included in feed, but the effect varies by the inclusion rate, food level contamination, feed´s moisture and the type of acid. Formaldehyde is permitted in some countries; therefore, it is corrosive and potentially harmful for humans and animals.

Appropriate pelleting process can eliminate *Salmonella* by heat treatment; it is performed at 93°C for 90 s [17]. Combinations of several of these treatments have been shown effective in recontaminated feed. Measures to prevent recontamination of finished feed should to be taken.

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