On-farm risk factors associated with Salmonella in pig herds

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ABSTRACT

In the pig production *Salmonella* infections are cause of concern for two major reasons. The first is the clinical disease in pigs and the second is that pigs can be infected with a broad range of *Salmonella* serotypes which can potentially contaminate pork products and pose a threat to human health. In Europe, salmonellosis is the second most frequent zoonoses for number of confirmed human cases and number of hospitalizations. After eggs, the consumption of contaminated pork meat and meat-product is the major cause of human outbreaks. According to the most recent survey conducted on pig farms in the EU in 2008, Italy was among the top five countries with the highest prevalence around 51.2% in breeding farms and 43.9% in production farms. These finding highlighting the need to investigate the risk factors in pig farms that should be managed to maintain a low prevalence. Pigs are susceptible to most *Salmonella* serotypes and although *S.* Typhimurium and its monophasic variants are the most common, a large variety of other serotypes are also reported in surveillance studies at farm level. Low *Salmonella* prevalence in pig herd is associated with a lower contamination pressure at the slaughterhouse reducing the occurrence of cross-contamination of carcasses during the slaughter process and, subsequently, the likelihood that human cases of salmonellosis will occur. This review focuses on risk factors in farms and biosecurity measures that can help to control pig important pathogens at the same time as reducing the within-farm prevalence of *Salmonella*. The main factors influencing *Salmonella* infection in pigs can be grouped into four different categories: farm hygiene, feeding practices, herd and health management. However, there is no universal protocol that all pig herds can put into place to minimize the risk of disease introduction or spread. Each farm is unique for host susceptibility, management, facilities, and other influential factors. Biosecurity measures, cleaning and disinfection, feed practices, as well as vaccination are often mentioned as the intervention categories with the greatest potential to reduce *Salmonella* prevalence in pig farms. The information included in this review may persuade the farmers that improving good hygiene practices and animal management would result in economic rewards. The efforts to control *Salmonella* in farms could also help to reduce infection by other porcine pathogens.

KEY WORDS

Salmonella; pig farms; risk factors; biosecurity measures, food safety.

INTRODUCTION

In the pig production *Salmonella* infections are cause of concern for two major reasons. The first is clinical disease in pigs (septicaemic salmonellosis associated with *Salmonella* Choleraesuis and enterocolitis associated with the broad host range serotype such as *S.* Typhimurium and its variant *S.* (1,4,[5],12:i:-), and the second is that pigs can be infected with several *Salmonella* serotypes that can potentially contaminate pork products and pose a threat to human health. *Salmonella* is the second most common zoonotic gastrointestinal bacteria in Europe with 91,857 confirmed human cases in 2018 [1]. However, this data represents just the tip of the iceberg as only the most serious cases are reported to the health department. Many other cases are not diagnosed because not all ill persons seek medical care and at healthcare-level not all the cases are reported to public health officials. Therefore, a more collaborative approach between human and veterinary medicine, in the context of the "one health" perspective is necessary.

The consumption of pig meat constitutes a source of human *Salmonella* infections [1]. Consequently, the main purpose of controlling *Salmonella* is to reduce prevalence within herds, prevent dissemination of *Salmonella* during later stages of production (i.e. to rearing and fattening pigs) and improve transport and slaughter hygiene. This dissemination may lead to *Salmonella* contamination of pig meat and consequently to human disease (Figure 1).

In Europe, after egg and egg products, bakery products and mixed food, consumption of pork and products thereof has been identified as 4rd most important source of *Salmonella* in human food-borne outbreaks [1].

For the pig chain, monitoring of *Salmonella* laid down by the meat hygiene criteria regulation (Commission Regulation - EC - No 2073/2005). This monitoring is based on the bacteriological analysis of the carcasses samples. Although, in case of a positive sample, it is difficult to establish whether tissue contamination originated from an infected farm or from cross-contamination at the slaughterhouse [2]. The subclinical and largely widespread *Salmonella* infection across the different production stages in pig farms makes that control at slaughterhouse level difficult and costly. However, some European

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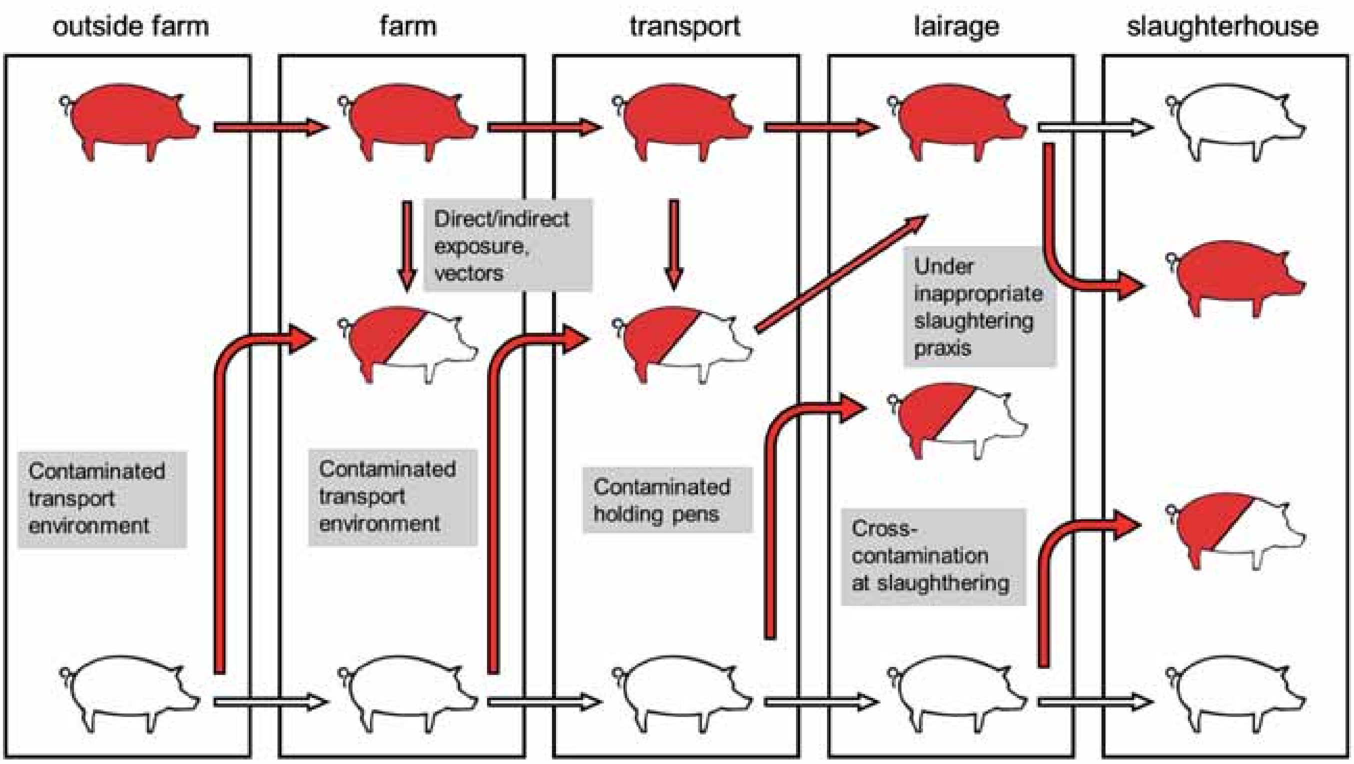

Figure 1 - Progress of infected or contaminated pigs (red) and Salmonella-free pigs (white) from farm to the slaughterhouse. Salmonella-free pigs can become infected or contaminated (red/white) during transport, in the holding pens, and by cross-contamination in the slaughter line (adapted from Arguello et al.[82]).

countries such as Danmark and German set up national control programmes based on serological testing of blood or meat juice samples collected from pigs at the abattoir [3, 4]. According to the serological results, pig farms are classified in one of three herd-levels [3, 5]. Highly infected herds, assigned to level 2 or 3, are supported by the national governments to reduce the infection load of their herd. Additionally, these farms are subjected to penalty fees to cover the expenses of the special hygienic precautions that have to be taken at the slaughterhouse when pigs from herd level 3 are slaughtered. Farmers are therefore motivated to apply better control measures to reduce *Salmonella* prevalence and avoid the financial consequences [3].

Pigs are susceptible to most *Salmonella* serotypes and although *S.* Typhimurium and its monophasic variants are the most common serotypes reported, a large variety of other serotypes can be isolated from pig farms [6].

It is widely acknowledged that infection in pigs is typically not associated with clinical disease, and pigs acting as "asymptomatic carriers" [7, 8]. However, some serovars such as *S.* Choleraesuis or *S.* Typhimurium and its monophasic variant along with other invasive serotypes (e.g. *S.* Enteritidis. *S.* Dublin, *S.* Newport) may result in clinical disease and septicemic episodes [9]. The impact of *Salmonella* on-farm performance is still not clear [10]. An American study reported that finisher pigs with high *Salmonella* prevalence had feed conversion rates above the median when compared with herds with lower prevalence [11] A more recent study from UK showed that pig farm with a low *Salmonella* seroprevalence (<10%) had a higher slaughter live weight (mean 103.7 kg), compared with conventionally control farm (mean 93.8 kg) [12]. Despite these findings, to date, there is no enough evidence to said that a lower *Salmonella* prevalence could result in higher productivity [10]. Although, *Salmonella* infection is often associated with other diseases such as postweaning multisystemic wasting syndrome (PMWS), resulting in decreased productivity [13].

Due to the lack of clinical infectious disease and economic losses, farmers and pig owners, do not see the need to intervene in order to reduce its prevalence at farm level as a priority. Likewise, the lack of any financial incentives or penalties in the majority of the EU member states may have led to the perception that *Salmonella* infection in pigs is of lesser importance compared to the other pig diseases or *Salmonella* in poultry [10].

According to the most recent survey conducted on pig farms in the EU in 2008, Italy was among the top five countries with the highest prevalence around 51.2% in nucleus and multiplier farms and 43.9% in production farms [14].

Several studies have shown that there is a strong association between *Salmonella* intestinal carriage of pigs at the herd level and the contamination pressure at the abattoir [15, 16]. Therefore, on-farm interventions and good control measures applied at farm aimed to reduce the prevalence of *Salmonella* positive pigs should prevent further spread within the production chain.

This review focuses on risk factors in pig farms and biosecurity measures that can help to control important pig pathogens at the same time as reducing the within-farm prevalence of *Salmonella*.

Several risk factors are associated with *Salmonella* prevalence in the herds. Following the classification used by some authors [17, 18] the main risk factors are grouped into 4 different categories (Figure 2):

1. Farm hygiene: cleaning and disinfection (C&D), boots,

rodents, animal vector, humans and vehicles, and manure management.
2. Feeding practices: type of feeding (pellets or meal; particle size, dry or wet) and acidification of feed.
3. Herd management: herd size, type of farm, all in/all out, quarantine and housing systems (type of pen and wall separation).
4. Health management: herd health status, vaccination and antibiotic treatments.

FARM HYGIENE

Cleaning and disinfection practices

It appears to be common sense that cleaning and disinfection (C&D) practices of pig pens are an essential part of any effective on-farm disease control regimen [10]. *Salmonella*-free pigs housed in a contaminated environment are likely to become infected [19]. However, the elimination of *Salmonella* from farm buildings is complex due to the robustness of the organism which is able to persist in the environment from months to years, especially when protected by residual organic matter (e.g dust and faeces) [20]. There are different types of disinfectant commercially available and effective against *Salmonella*, such as quaternary ammonium compounds (QAC), products containing glutaraldehyde or formaldehyde, iodine based compounds or chlorocresols and peroxygen or peracetic acid-based compounds [21].
However, their effectiveness may be severely compromised if not properly applied. Disinfectants can be easily inactivated by the presence of organic matter or overdiluted if used before the surfaces are completely dried [10]. In addition, most farm buildings have crevices and cracks in floors, ceilings and walls which are particularly difficult to clean properly [22]. It is important to mention that some types of pig house material can be more challenging to clean. Concrete is a common material used in pig accommodation and its rough surface is more likely to have a high level of residual contamination compared with smooth surfaces [23]. For careful and systematic C&D procedures also the tool and farm equipment (feeders and drinkers), are of paramount importance. Moreover, the presence of rodent vectors on a farm can hamper the effectiveness of any C&D procedures, as *Salmonella*-carrying rats and mice can re-contaminate the cleaned surfaces and recycle the infection from one batch to the next [21]. The general idea is that only a frequent cleaning regimen after every movement of pig group and linked with all in/all out (AIAO) management could lead to sustainable success [10]. A recent study showed that an increased frequency and efficiency of cleaning practices on-farm reduced the prevalence of *Salmonella* Typhimurium shedding at the time of slaughter. However, the authors found that these efforts alone were not sufficient to eliminate the infection from the pig population [24]. To control the infection in pigs and reduce the level of *Salmonella* shedding under the infection dose (10^3 CFU/g), it is necessary to combine the cleaning procedures to other appropriate measures such as vaccination and acid treatment of feed [24].

Boot dips

Similarly, to the C&D, the use of boot dips containing disinfectant is a procedure commonly seen as good biosecurity measures. The correct use of boot dips is associated with a lower prevalence of *Salmonella* infection [10]. Ideally, the footwear should be wash first before dipping to remove organic matter that severely depletes the disinfect activity. On the other hand, the incorrect use of boots and boot dips could potentially become a risk factor for *Salmonella* and a source of spreading the infection through the farm [25, 26]. Commonly in farms, the boot dips are not efficacious and became inactive due to contamination with fecal matter, mistakes with the dis-

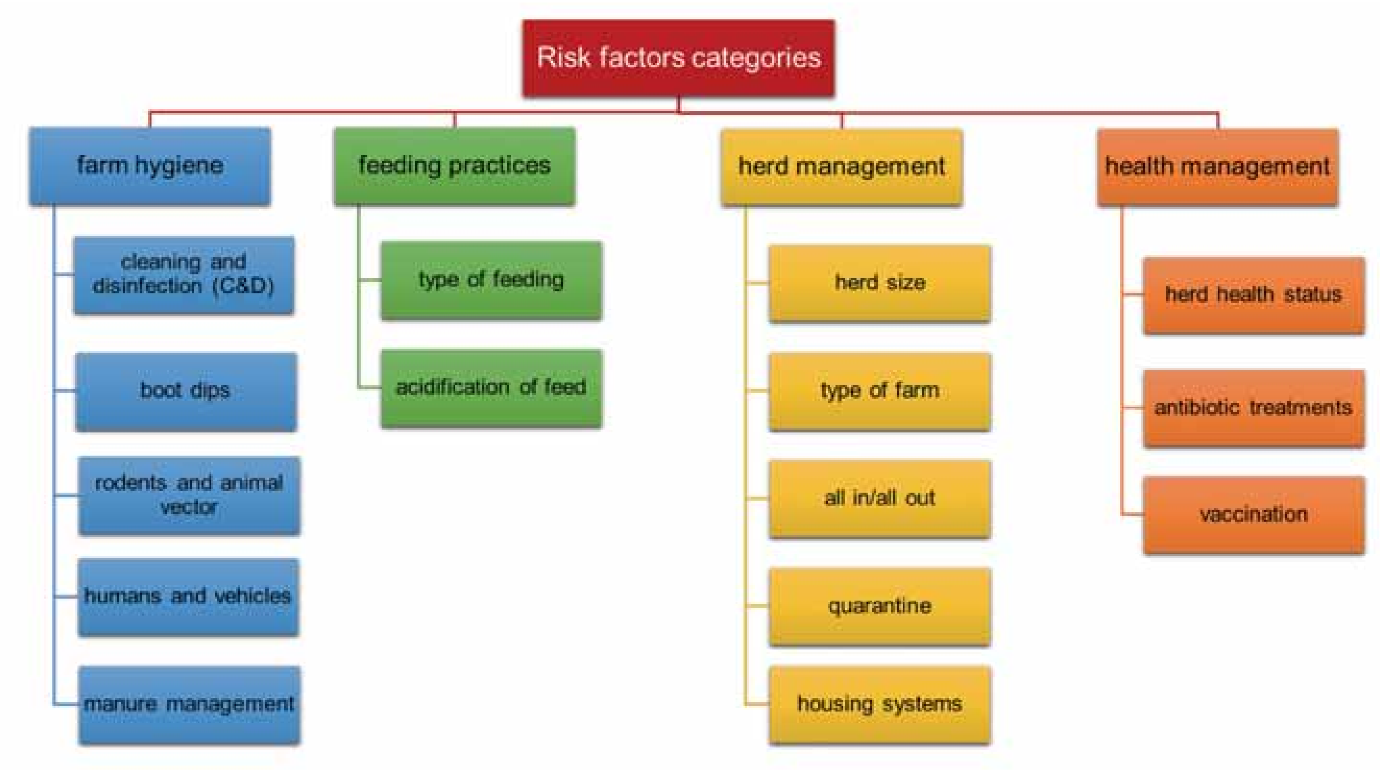

Figure 2 - Main risk factors associated with Salmonella prevalence within herds.

infectant concentration used, or not respecting biocidal expiry dates [27]. Environmental factors such as hot weather and rain may also influence the efficacy of the dips by increased evaporation or dilution by rainwater. The use of a cover for the dips may help to prevent environmental factors from compromising the dips. It is important to frequently change and replenish the dips at least twice a week [27]. If not used correctly the efforts are vain and result in wasting resources, time and money.

Animal vectors

Since members of the *Salmonella* are notorious for their ability to infect a wide range of hosts, contact with other animal species (domestic, wild or synanthropic) can increase the pig's risk of infection [28, 29]. The role of carrier vectors that can contribute to the horizontal transmission of *Salmonella* and other pathogens (e.g PCV2, PRV, *Toxoplasma gondii*, *Lawsonia intracellularis*) has been well documented. Rodents, wild birds, insects, and pets (dogs, and cats) are common inhabitants living on pig farms that can all potentially introduce and transmit *Salmonella* by direct contact with pigs or via faecal contamination of feed, drinkers or farm equipment [30]. Among them, wild birds and synanthropic rodents (mice and rats) are of particular importance [30, 31]. A recent study showed that wild birds can be infected with the same serotype of pigs, suggesting that wild birds are capable of recycling infection and contributing to the persistence of *Salmonella* between batches of pigs [32]. Rodents can acquire and persistently carry *Salmonella* infection for several months [33, 34]. On farms, rodents are considerate very efficient vectors and amplifiers of *Salmonella* infection, due to their high *Salmonella*-carriage and their good reproductive capacity. Mouse droppings can have up to 10^4 CFU/g of *Salmonella* and a single mouse could shed 100 fecal pellets per day [33, 35]. Pest control on-farm is of paramount importance due to their ability in transmitting several pig pathogens but also because of the economic damage that they can cause to the farm infrastructure and the amount of feed that they can consume [36]. Poison and traps are the most common methods of rodent control. An efficient pest control rodent should have an integrated approach which includes the use of rodenticides and strict biosecurity procedures focussed on repairing facility structure (holes, door seals, etc.), disposal of dead animals and waste and removal of pig's leftover feed [35]. Moreover, training the farm staff to respond more quickly and thoroughly to signs of rodents can be very helpful [10].

Humans and vehicles as vectors

Biosecurity-related practices regarding visitors and vehicles have been reported to be useful in lowering the risk of *Salmonella* infection in pigs farm [29]. Moreover, other important pig pathogens can be carried by humans, for example, *Mycoplasma hyopneumoniae* and foot and mouth disease virus have been found to survive in humans for 30 and 11 hours respectively [37]. Therefore, often pig farms demand that visitors 24 to 48-hours pig free and to shower before access into the farm. Good practice as the presence of areas where visitors can change clothes and footwear before entering help to reduce the risk of spread *Salmonella* into pig areas. Similarly, because humans can act as mechanical and biological vectors, access to toilets and handwashing have a protective effect against *Salmonella* for pigs and people as well [11, 38].

Transport vehicles are constantly in contact with other farms and slaughterhouses and can transfer pathogens from one farm to another, acting as mechanical vectors [39]. Due to the considerable risk that they represent if possible should be farm dedicated. Otherways, a rigorous biosecurity regimen of vehicle disinfection is essential. This required an adequate wheel wash and spray disinfection or a dedicated disinfection station, but these procedures are expensive and not commonly applied even in large pig farms. Alternatively, any external vehicles (lorries and visitor's cars as well) should not be allowed to enter into the clean areas of the farm and parked at least 300 meters away from animal buildings [10].

Manure management

Manure can be a source of many important pig's infections such as swine dysentery (infection with *Brachyspira* spp.), classical swine fever, foot and mouth disease, porcine reproductive and respiratory syndrome (PRRS), *Streptococcus suis*, *Escherichia coli* and *Salmonella*. The risk of introduction and spreading infections increases considerably if manure from other farm facilities is spread within 3.2 km of a pig farm [10]. Pig slurry should be stored as long as possible and under controlled conditions (10.5°C for 84-112 days) to reduce or kill *Salmonella* and other organisms irrespective of the initial load[39, 40]. Several technologies are designed in order to reduce microbial concentrations contained in the pig manure by 90 to 99% [41]. Manure treatment systems are generally physical, biological and chemical or a combination of all three treatments and rely on anaerobic digestion, composting, and separation technologies [35, 41].

Well-designed farm facilities should avoid the accumulation of feces and contact between animals and their waste. A French study showed that a frequent removal of the sow's manure during the lactation period decreases the risk of *Salmonella* infection in piglets. The same authors reported that emptying the pit below slatted floors after that a batch of sows was removed is a protective factor against *Salmonella* [18]. Types of floor which decrease pig contact with fecal material and decrease fecal-oral transmission among pigs should be preferred. A lower *Salmonella* prevalence was found in pigs housed on fully slatted floors, were feces immediately flow away in the manure pit, than in pigs raised on the flush gutter floor [42]. While pen with earth floors have been associated with a higher *Salmonella* prevalence [43]. Today it is generally accepted that solid or partially slatted cause a higher risk for *Salmonella* compared with fully slatted floors [30, 31, 44].

FEEDING PRACTICES

Type of feeding

Feed-practices are considered to be of maximum importance to control and reduce *Salmonella* prevalence within herds.

The feed nature (meal wet or dry), proportions of ingredients and particle size have been reported to influence the risk of *Salmonella* infection in pigs [12, 29, 38]. There is a general consensus among authors that dry meal is preferred to pelleted feed and wet feed is preferred over dry feed. The principle behind this is that both meal and liquid feed reduce the intestine pH creating an inhospitable environment for *Salmonella* [45]. Many studies available have proved the protective effect of wet feed compared to dry feed [12, 18, 38, 46, 47]. However, it is important to highlight that liquid feed alone with no acidic condiction achieved by fermentation, is not sufficient to provide protection [25]. On the contrary, the use of trough feeding water without the fermentation step was reported to be a risk factor for *Salmonella* infection [46]. Additionally, a ration with 25% of barley and wheat (such as maize, beet, manioc), have been associated with a reduction of *Salmonella* infection in pigs [48, 49]. The feed particle size may be responsible for higher *Salmonella* prevalence in pigs. Small particle fractions used to make pellets are considered a risk factor due to the quicker transit passage through the pig digestive tract which does not result in a low intestinal pH. While the slower gastric passage and the lower gastric pH when pigs are fed a coarsely versus with finely ground feed are reported to be protective [50].

It is important to mention that the animal feed can be a source of introducing *Salmonella* serovars and resistant bacteria into pig farms [29, 51, 52]. Feed ingredients may be accidentally contaminated by *Salmonella* during growth, harvesting, transport, or storage. Additionally, on-farm feedstuff contamination, in particular of cereals, can result from the through contact with wildlife or synanthropic animals that defecate in crop or storage facilities or by the usage of contaminated equipment [53, 54]. A multi-country survey carried out in five EU countries detected *Salmonella* from feedstuff in 17.6% of pig farms and 6.9% of all feed samples, highlighting the role of feed as one of the major sources of persisting infection in pigs [29].

Acidification of feed

Several studies have investigated the action of substances as organic acids, probiotics, prebiotics, formaldehyde, essential oils and bacteriophages, regarding their ability to modify the gut environment to prevent *Salmonella* colonization. Among those interventions, the acidification with organic acids added to the feed or drinking water seems to be the most popular. Formic and propionic are the main acids used as inhibitors against *Salmonella* however their efficacy is reported to be inconsistent [55]. The beneficial effect is highly variable and depends on the type of organic acid administered, the inclusion rate and the physical and chemical form of the product (acid or acid salt) [51, 52]. For example, the administration of lactic acid to weaner [56] and grower [57] pigs and formic acid to finisher pigs [58] were found to have a beneficial effect against *Salmonella*. Contrary, in another study, the acid-supplemented feed to weaners did not decrease the prevalence of *Salmonella* in their feces [59]. It has been hypothesized that also the high level of bacteria contamination, the presence of other concurrent diseases in herd, the wrong compound administration (not for a sufficiently long period) and the "acid tolerance response" acquired from the organism may also contribute to the failure of the activity of the organic acids [10, 51]. In conclusion, the problems associated with the use of acid substances such as clogging of drinkers, fungal growth, corrosion of the equipment, along with the uncertainty regarding their effect, make the advice difficult in terms of cost-benefit [10].

HERD MANAGEMENT

Herd size, types of farm and all in/all out (AIAO) management

The herd size is considered a controversial risk factor for *Salmonella*. Large companies are associated with a higher risk of infection due to practices of mixing pigs, which may happen most frequently in large herds [60]. On the contrary, there are observations that suggest that *Salmonella* can be more prevalent in small or medium-size herds [47]. Large farms can be very well managed with good C&D procedures or other practices successful in controlling *Salmonella* prevalence such as batch farrowing and AIAO management [61].

The herd size is also associated with livestock management aspects that can potentially increase the risk. Large companies may need to replace or purchase animals but they can also operate as a closed herd breeding their own replacements. As widely accepted that operate a closed herd system is desirable in order to prevent the introduction of infected animals into the farm. In this type of farm, pis are generally exposed to farm-resident *Salmonella* strains and can acquire a herd immunity able to control the infection reducing the carrying and shedding of specific resident strains [10]. However many pig producers consider the closed system impractical and they regularly introduce pigs into the main farm. In Denmark, a strategy to minimize the risk associated with this animal flow is to import pigs from farms having an equal or superior health status [62]. Some authors also report that having more than two suppliers was a risk factor [38, 63]. However, pig flow practices if associated with strict age group segregation and AIAO policies can result in an efficient strategy to decrease *Salmonella* exposure and infection [29]. The AIAO is generally thought one of the most important interventions to reduce disease in pig farms. Although there are not many studies that have specifically proved the association of this practice with the reduction of *Salmonella* prevalence. Canadian and French studies showed that strict application of AIAO procedures have lent to a decreasing of *Salmonella* infection [18, 64, 65]. In contrast, American and Danish studies did not found in the AIAO system a protective effect against *Salmonell*a. Despite all these contradictory findings, minimizing the animal movement around the farm, strict management of group of pigs as well as the presence of quarantine facilities are considered of paramount importance for the successful control of *Salmonella* and other diseases.

Quarantine, isolation and pen partition

The isolation of the new pigs on arrival is often ignored. Quarantine facilities allow animals to recover from the stress of transport, adapt to a new environment and showing symptoms of any incubating infections in a contained environment [39]. This isolation period is also an opportunity to run laboratory tests, challenge with resident pathogens and perform vaccination if appropriate. Regarding *Salmonella* the majority of the authors recommend keeping the replacement animals in isolation for six weeks with no cross-contact with the main unit [39]. Where possible, quarantine building should be located at 100 to 150 meters far away from the main farm and it should be run as a completely independent unit with its own farm equipment, and waste management system. It is preferable to have their own farm staff in charge of managing the quarantined animals, if not possible the animals should be visited at the end of the working day [10]. Isolation premises should adopt AIAO systems and operated with strict biosecurity measures with particular attention on C&D procedures between batches of pigs and the use of different protective clothing before entering and after leaving the isolation building [38]. In fattening farms where the pigs are introduced to multiple age sites, the use of quarantine arrangements is not always practicable. There, it is important to have a good separation between buildings housing animals from different ages and minimize the use of any common equipment between different risk categories [10]. Authors agree that the snout contact between pigs in neighboring pens is considered a significant risk factor. Pens allowing for nose-to-nose contact between pigs had 2.2 times higher odds to be *Salmonella*-positive than pens without such contact [30, 66]. Closed partitions between pens are feature inherent to farm design and not easy to change. However, pen partition is an important barrier to prevent the seepage of contaminated material between adjacent pens and the spread of pig important pathogens, therefore it should be taken into account during the design of new barns [30, 67].

HEALTH MANAGEMENT

Herd health status

It has been said that the high health status of herd (e.g membership in specific free) is associated with a lower *Salmonella* risk of infection, suggesting the presence of synergy between control pig pathogens and control of *Salmonella* [10, 29].

Diarrhea problems caused by pathogens that damage or disrupt the gut and its flora may predispose or affect *Salmonella* infection [68]. Likewise, co-infection with the other pig pathogens itself could play a role in *Salmonella* epidemiology, probably due to interference with the host's immune response [12]. *Lawsonia intracellularis* infection was associated with an increased prevalence of pigs shedding *Salmonella* at the end of the fattening period [18]. A recent study found that the vaccination against *L. intracellularis* was able to reduce the shedding of *S.* Typhimurium in co-infected pigs [69].

PRRSV infection was also identified as a risk factor for *Salmonella* shedding due to the ability of the virus to induce immunodepression leading pigs more susceptible to *Salmonella* contamination and multiplication [18].

A couple of researches investigated the interactions between parasites and bacteria, suggesting that nematodes in particular *Oesophagostomum spp*. [70] and *Ascaris suum* [71] might play an important role in the dynamics of *Salmonella* infections.

The associations between the herd health status and *Salmonella* prevalence may reflect the overall expertise and management practices of the pig farmers [29].

In many ways, *Yersinia* and *Salmonella* have similar behavior and some practices like limiting the mixing of pig batches during the fattening period appear to be effective in controlling both infections [17].

As previously stated, *Salmonella* infection is often subclinical and thus pig owners do not usually see the need to intervene, as they consider *Salmonella* problem a consumer's responsibility by "proper cooking". Nonetheless, if actions against *Salmonella* would result in better control of other serious pig pathogens, that might motivate the farmers to improve *Salmonella* controls [10].

Antibiotic treatments and vaccination

The usage of antibiotics is another controversial risk factor. Prophylactic antibiotic treatment or the use of antibiotics growth promoter (e.g tylosin) during the fattening period was observed to enhance the risk of *Salmonella* shedding [12, 47, 72]. A German epidemiological survey found that pigs treated with antibiotics had a five times higher chance to be seropositive for *Salmonella* compared with the untreated animals [44]. All the authors agree on the plausible explanation for this intriguing finding, suggesting that the alteration effect of antibiotics on the normal protective gut may have favored the colonization of endogenous pathogens. In contrast, two American studies found a higher prevalence of *Salmonella* in antimicrobial-free production systems compared with conventional ones [73, 74]. Despite these studies, there is still no compelling evidence to show that antibiotics can help to lower *Salmonella* prevalence. Conversely, probiotics and prebiotics may help to reduce the infection by promoting protective gut endogenous flora [75, 76].

The use of vaccination might be a suitable alternative to the use of antimicrobials for controlling the *Salmonella* infection cycle in pig farms. Currently, many *Salmonella* vaccines induce an antibody response against the lipopolysaccharide layer of the bacterial wall, and thus the DIVA status (differentiation of infected from vaccinated animals) is not possible [77, 78]. This can potentially interfere with herd-level serological monitoring programmes for *Salmonella.* To overcome these limitations, a strategy could be to vaccine only to the sows rather than finisher pigs, aimed at providing passive immune protection to whose piglets without interfering with any monitoring serological programs in place [77]. In general serovar-specific vaccines have been reported to be the more effective, this raised the issue of the low cross-protection against more than one serogroup. In farms where multiple serovars are present, the efficacy of the vaccination may be compromised and can cause the emergence and spread of the other serovars [79]. Ideally, should be prioritized the control of serovars that pose the highest risk to humans. In fact, it has been speculated that vaccination of pigs with *S.* Typhimurium together with good biosecurity measure help to reduce *Salmonella* prevalence in pigs and the proportion of "carrier" animals at the slaughterhouse [80]. It is important to note that vaccination is not a cheap strategy and alone is not sufficient to eliminate the infection [81]. There is a general consensus that an holistic approach covering different interventions such as vaccination, biosecurity measures, C&D procedures and feeding practices is required in order to reduce the prevalence of *Salmonella* in pigs.

CONCLUSION

Control of *Salmonella* in pig meat as a public health problem should be based on individual State epidemiological situations covering the whole production chain from farm to fork. Owing to the characteristics of the infections and the ability to survive in the environment, the *Salmonella* control on-farm should be considered as part of a holistic plan. Effective control strategies should combine different key interventions of biosecurity, C&D, feed practices and vaccination.

Hygiene is extremely important in intensive pig production. Despite careful and systematic C&D procedures, good hygiene practice also involves physical segregation of animal groups and the prevention of re-contaminate by vectors, personnel and equipment. The use of acidified feed and water may further potential benefits but highly expensive for the farmer. Moreover, there is a need for a more complete evaluation of their efficacy not always consistent. In the era of antimicrobial resistance, any control strategy should also include the reduction of antimicrobial treatments. The use of the current vaccines against *Salmonella* for pigs might be a suitable alternative to antibiotic use.

However, further investigations are needed to avoid interference between vaccination and serological monitoring schemes. Even when productivity benefits can be demonstrated, it can still be difficult to motivate farmers to apply improved standards. There is therefore a need for a greater understanding of the drivers and barriers involved in promotion of voluntary improvement of farm standards.

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