Risk factors associated with *Salmonella* prevalence on swine farms

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Summary

This article reviews on-farm risk factors that have been associated with the prevalence status of *Salmonella* in swine. Salmonellosis is the second most common etiological cause of bacterial human foodborne illness in the United States, and most cases can be attributed to contaminated food products. Reduction of human foodborne salmonellosis has become a public health priority both nationally and internationally. Public health concerns, increased stringency of regulatory limits at slaughter, and competition for international market share are likely to increase interest in on-farm *Salmonella* control.

Keywords: swine, *Salmonella*, prevalence, risk factors

An estimated 1.5 million cases of nontyphoidal salmonellosis in humans occur yearly in the United States, and nearly all cases are foodborne.[1] This tremendous burden on public health has made reduction of human salmonellosis a key public health objective.[2] Salmonellae are ubiquitous organisms, and the vertebrate gastrointestinal tract is considered to be their biological niche. Although infection may result in clinical disease, it has long been recognized that swine may be asymptomatic carriers of salmonellae.[3–12] In the United States, the number of farms positive for *Salmonella* has been estimated to range from 38.2 to 83%, and the number of positive pigs from 6 to 24.6%.[13,14]

Beyond the potential impact on domestic public health and market stability, contamination of pork products with salmonellae may put the pork export market at risk.[15,16] With the coordination of "farm-to-table" *Salmonella* control programs by many European pork producers (among the United States' major competitors for export markets),[17] demonstration of effective control measures may be important for maintaining international market share. Yet wholesale adoption of pre-existing control programs may not be practical in the United States due to differences in production systems, industry structure, and regulatory organization.

Significant strides have been made at decreasing *Salmonella* contamination in one link of the US pork chain, namely, at slaughter and processing. The Pathogen Reduction: Hazard Analysis and Critical Control Point (HACCP) Systems[18] established performance standards at slaughter and processing plants, which has resulted in decreased contamination of product with salmonellae.[19] It is expected that standards at slaughter and processing will become more stringent, creating pressure from packers and processors to reduce prevalence of *Salmonella*-positive swine through on-farm interventions.

The focus of this review is on the on-farm risk factors for *Salmonella* infection in swine, that have been identified through epidemiological investigations. Promising interventions that have thus far been described predominantly in experimental settings (vaccines, antimicrobial treatments, and competitive exclusion) are not included. Additionally, potential risks beyond the "farm gate" (eg, exposure during transport and lairage and contamination of carcasses during slaughter) are not included in this review for the main purposes of brevity and a focus on potential on-farm interventions. It is also important to recognize that most reviewed studies have been conducted in European herds, and the epidemiology of *Salmonella* infection, as well as the impact and feasibility of interventions, may not be directly applicable to the situation in US herds. Yet these risk factors suggest promising areas for further investigation of *Salmonella* control on US swine farms, and many warrant further investigation (which should include field trials) of their efficacy under US management systems.

In a 1996 review of the literature,[20] "total farm hygiene" was identified as the most important risk factor for *Salmonella* infection. "Total farm hygiene" was defined broadly by the authors to encompass many aspects of swine production techniques that might be considered good production practices, including cleanliness, housing, biosecurity, feeding practices, water source, and antimicrobial use. For the most part, the literature since that period has continued to focus on these "hygienic" approaches to *Salmonella* control.

Humans as vectors

Biosecurity-related practices regarding swine farm personnel and visitors have been associated with decreased risk of infection of swine with salmonellae. Researchers have found that hand washing[21] and access to toilets and hand-washing facilities[22] have been associated with decreased *Salmonella* prevalence on swine farms. Provision of areas where clothes and footwear could be changed prior to entry into pig areas was

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associated with reduced *Salmonella* seroprevalence in Danish market swine,[21] but not in Dutch herds.[23] It has also been reported that in herds with relatively more humans on site daily, there was an increased risk of high fecal shedding of salmonellae,[22] suggesting that increased human traffic on farms increases the pigs' risk of infection. It is unclear whether personnel hygienic practices are directly related to risk of infection of pigs with salmonellae or simply serve as a proxy measure of a pork producer's overall attitude about biosecurity. It does suggest that improved personnel hygiene may be an important intervention for infection of swine with salmonellae. The relatively small cost incurred may be offset by decreased transfer of other performance-impairing pathogens.[24,25]

Flooring types

The type of flooring on which pigs are reared has been evaluated in epidemiological investigations. The biological premise for its importance is that certain types of flooring decrease pig contact with fecal material, resulting in decreased fecal-oral transmission among pigs. *Salmonella* prevalence was lower in swine housed on fenestrated flooring (eg, concrete slats) than in pigs housed on flush-gutter flooring.[13,26]

Housing contamination

Contamination of the resident environment of animal housing has been implicated in many studies as a source of *Salmonella* infection.[7,27–34] Salmonellae are capable of surviving 6 years or more in the environment,[35,36] and the challenges of cleaning and disinfecting animal housing are well documented.[37–40] Concrete, a common material for swine flooring, is a difficult surface to clean and disinfect. After cleaning and disinfection of swine housing facilities, rough-surfaced concrete was more likely to have high levels of residual contamination (measured by aerobic plate counts) than smoother surfaces.[39] Substandard cleaning and disinfection may allow *Salmonella* organisms to remain as contaminants on floors, as determined by culture.[41] Surprisingly, in the Netherlands, the odds were greater for higher *Salmonella* seroprevalence in production systems where barns were cleaned and disinfected between groups of pigs compared to systems in which floors and buildings were cleaned but no disinfectant was used.[23] The authors speculated

that producers who use disinfectants clean less adequately, with the idea that remaining microbes will be dealt with by the disinfectant. Terminal disinfection, either through fogging or fine mist of formaldehyde, decreases but does not eliminate *Salmonella* contamination in poultry houses.[38–40] Human health risks are associated with use of formaldehyde, and the benefits of its use as a disinfectant should be considered. To date, no controlled field trials have studied the impact of cleaning and disinfection practices on *Salmonella* prevalence in swine. Although it appears to be common sense to reduce contamination of the pig's environment, there is little indication as to what cleaning and disinfection protocols are most effective for *Salmonella* contamination control, let alone the economic feasibility of these interventions. There is a need to evaluate the components of cleaning and disinfection practices in use that are both effective and feasible for reduction of *Salmonella* contamination in swine housing.

Pig flow management

Pig flow practices that are well recognized as important for reducing production-impairing swine diseases (ie, all in-all out pig flow)[42–44] are often suggested for *Salmonella* control, yet few studies identify the association of this practice with decreased *Salmonella* prevalence. The biological premise is that the combination of cleaning and disinfecting the facility between groups of pigs and segregating age groups decreases the potential for *Salmonella* exposure and infection. On Danish farms that used all in-all out production management and also provided areas for personnel to change clothing and boots prior to entering or leaving the pig areas, herds were nearly three times less likely to be seropositive than on farms that did not use these management practices.[21] There was no reduction in risk of having a seropositive herd on farms that did not use both practices, ie, that either provided a changing area or used all in-all out flow, but not both. On the other hand, in another study of Danish swine, all in-all out pig flow was associated with increased *Salmonella* seroprevalence, although this result was based on a crude odds ratio, not adjusted for other management practices on the farm.[45] *Salmonella* prevalence may be high on farms with all in-all out production. In a study of three-site production systems with all in-all out

management in the United States, *Salmonella* prevalence in finishers ranged from 0% to more than 70%.[22] The limited and contradictory evidence for all in-all out pig flow as a means of *Salmonella* control warrants further investigation prior to its recommendation for that specific purpose.

Importance of sow-to-pig transmission

Many investigators have reported relatively high *Salmonella* prevalence in breeding gilts and sows.[41,46,47] Beyond the food safety risk when the sow ultimately enters the food chain, the importance of vertical transmission from the sow to her offspring has been only minimally addressed. Several authors have demonstrated that piglets may be infected early in life.[6,41] Efforts to use segregated early weaning to prevent sow-to-pig transmission has had mixed results that are likely to be at best farm-specific in success.[48–50] It is paradoxical that *Salmonella* serovars isolated from a sow often differ from those isolated from her piglets,[41] which might be explained by sampling error, colostral protection, or differential infection efficiency of serotypes in pigs of different ages. Recent epidemiological surveys in Denmark[51] have suggested that pigs produced from sow herds with high *Salmonella* seroprevalence are at greater risk for isolation of the specific serovar *Salmonella* Typhimurium.

More research is necessary to evaluate the importance of the sow's *Salmonella* infection status on the risk of infection in her offspring. If the sow herd is identified as a major source of exposure to *Salmonella* infection for growing pigs, this has important implications for the breadth and costs of surveillance and control programs.

Risk to swine posed by other vertebrate species

Since all vertebrates are susceptible to infection with *Salmonella* serovars, contact with other animal species may pose an infection risk to swine herds. The risk posed by having other domestic species on a farm with swine has been variable in the literature. Having other domestic animals on the same farm as finisher pigs has been associated with increased *Salmonella* prevalence.[22] However, many other researchers have found no association between *Salmonella* infection and the presence of domestic animals other than the target species.[24,40,52–54]

Domestic cats residing on swine farms may shed salmonellae.[55] Pests (eg, rodents, wild birds, and other wildlife species) have often been implicated as potential sources of salmonellae for swine. Several investigators have demonstrated that mice and rats on farms may be infected with salmonellae, often with the same serovars as the domestic species investigated.[55–60] Many cross-sectional investigations have isolated *Salmonella* organisms from free-living birds at prevalence rates ranging from 0% to more than 50%.[61–65] There is circumstantial evidence that sea gulls were responsible for two *Salmonella* outbreaks in Scotland.[61,63] Wild birds near broiler houses have been found to shed salmonellae at relatively high frequencies.[65] Foxes near poultry farms have been identified as shedding salmonellae.[60]

Economic benefits of pest control on farms, external to *Salmonella* control (eg, prevention of building damage and control of other diseases), may offset the costs of pest control, justifying these interventions and possibly also resulting in decreased *Salmonella* risk for swine.

Risks posed by invertebrate species

It has been recognized that flies[55,60] and beetles[60,66] (both mature and immature stages) may be vectors for *Salmonella* organisms. In fact, recent research suggests that the free-living nematode *Caenorhabditis elegans* may be persistently infected with salmonellae.[67] Although no epidemiological investigations have been performed to discern the attributable risk associated with invertebrate species, it appears that they may at least serve as potential reservoirs and vectors on farms.

Risk factors associated with feed

Risk factors associated with feed may be divided into two major categories: feed as a source of salmonellae due to contamination, and the impact of feed ingredients and physical structure on *Salmonella* prevalence.

Feed as a source of *Salmonella*

It is well recognized that animal feeds and feedstuffs may be contaminated with salmonellae (Table 1).[19,41,68–70] It has been demonstrated in experimental settings that animals may become infected as a result of consuming contaminated feed.[70] There is

Table 1: Frequency of *Salmonella* isolation from swine feeds in selected reports

Reference*	Sample origin†	No. of samples	No. of sites sampled‡	No. of samples positive (%)	No. of sites positive (%)‡
Davies and Wray (1997)[75]	M	3075	9	465 (15.1)	9 (100)
Fedorka-Cray et al (1997)[49]	T	549	22	4 (0.7)	5 (22.7)
Harris et al (1997)[69]	F, S	1264	30	35 (2.8)	14 (46.7)
Funk et al (2001)[22]	F	800	2	2 (0.25)	1 (50)

*   Superscripts identify reference numbers used in the text.

†   F: samples from feeders in barns; M: spillage and dust samples from a feed mill; S: samples of feed ingredients and complete feed from storage bins; T: swabs of internal compartments of truck grain boxes and feed ingredients.

‡   Sites include feed mills, trucks, and farms.

no doubt that appropriate process control and decontamination steps are needed during feed processing to reduce contamination of feedstuffs and thus avoid dissemination of contaminated feed to herds.

There is justification for questioning the relative importance of the role of contaminated feed in the epidemiology of *Salmonella* infection on swine farms. Most notably, *Salmonella* Typhimurium, a serovar often associated with foodborne disease in humans, is infrequently isolated from animal feeds in the United States or elsewhere.[21,41,69] In a multi-country survey in Europe, salmonellae were isolated from feedstuffs in 17.6% of herds and 6.9% of all samples.[21] However, the *Salmonella* serovars isolated from the feeds were not the same as those isolated from pigs on the farms.

Feed components and physical structure: Dry, fine, and pelleted

Epidemiological investigations, predominantly in Europe, have repeatedly demonstrated that feed composition and structure are associated with *Salmonella* prevalence in pigs. Among factors that have been identified are feeding either wet or dry diets, acidified diets (feed, water, or both), feed particle size, feed form (pelleted or meal), and heat-treated or non-heat-treated feeds, as well as actual feed ingredients.

Many investigators have reported that swine herds fed dry diets were at increased risk of high *Salmonella* seroprevalence.[21,23,34,71] It is important to note that wet feeding in

Europe often includes a fermentation step or addition of organic acids to prevent feed spoilage. In fact, trough feeding (adding water to feed with no preservation step) was associated with an increased risk of having a *Salmonella*-positive culture from pooled fecal samples in swine herds in the Netherlands.[71]

Whey feeds and acidifiers

A liquid whey product is usually used in diets containing whey, and is often the liquid used in fermented feed. In 1987, van Schie and Overgoor[72] reported that in swine herds in the Netherlands in which liquid whey was fed as part of the diet, prevalence of *Salmonella* was lower than in herds in which the feed was moistened with water. In another study,[21] herds fed whey were at decreased risk of being seropositive. Investigators hypothesized that a component of this effect may be related to the acidic pH of whey. Interventions using organic acids to decrease the pH of pig feedstuffs or water, mimicking the effect of whey, have had varied results in field intervention trials. In one peer-reviewed study,[73] *Salmonella* seroprevalence was significantly lower when organic acids were administered in the drinking water in one of three herds that received proper administration of the acidified water, while in the other two herds there was a trend toward lower seroprevalence that was not statistically significant. The limited clinical trials regarding the impact of organic acid administration have been predominantly published in nonrefereed scientific meeting proceedings.

It is uncertain whether feeding organic acids is an efficacious intervention for *Salmonella* control on swine farms. At best, current knowledge suggests that it is of variable benefit. Although organic acids may be corrosive to metal and concrete, addition of organic acids to dry feeds or water sources may be more easily accomplished within the current US feed manufacturing and delivery infrastructure than by implementing fermented liquid feeding systems. Further evaluation of the effects of acidic pH and fermented feeds on *Salmonella* infection prevalence is needed to evaluate their effects within commercial production settings.

Pelleting of diets and particle size

Pelleting of feed has long been recommended as a means of decontaminating pig feeds.[74] However, pelleting must be appropriately conducted, especially during the cooling phase of production, for all organisms to be destroyed.[75,76] Contrary to these recommendations, epidemiological studies have found that pigs fed pelleted rations were at increased risk of high *Salmonella* seroprevalence compared to those fed diets in meal form.[21]

Investigators have hypothesized that the biological mechanism responsible for higher *Salmonella* infection prevalence in pigs fed pelleted feeds (compared to those fed meal feeds) may be a result of smaller particle size, heat treatment, or the pelleted form. Few peer-reviewed clinical trials investigating the effect of feed form have been published. Further work is necessary to evaluate the mechanism behind the higher *Salmonella* prevalence associated with pelleted feeds.

Environmental temperature and season

Groups of North Carolina finisher pigs with high *Salmonella* prevalence were at greater odds of having been sampled in winter and spring (approximately late November through late June).[22] In the same study, pigs reared during periods of wide variation in daily high temperatures were at greater risk of high *Salmonella* prevalence.[22] These results are similar to others in which increased seroprevalence was reported during the fall and winter in Danish swine.[77]

Cool weather ventilation of swine barns is a compromise between maintaining adequate air exchange while conserving heat, which may result in periods when ventilation is not optimal. Unpredictability of weather conditions makes proper setting of ventilation systems difficult. Improper ventilation or temperature stress might be a biological explanation for the association of weather with *Salmonella* prevalence. What makes further evaluation of this risk factor promising is that there are advantages to production performance and pig health when proper ventilation is maintained in swine buildings, which could help offset extra costs associated with improved ventilation engineering and management.

Stocking density and marketing group effects

In a study of US swine, groups of finisher pigs categorized as having high *Salmonella* prevalence were more likely to be stocked at higher pig densities (ie, less space allowance per pig) at the time of sampling, compared to low prevalence groups.[22] In this study, initial stocking density was standardized by farm standard operating procedures, so the variation at the time of finisher sampling was accounted for by the number of pigs that had been marketed prior to sampling. One possible explanation for this finding is that transmission or shedding of salmonellae is reduced among pigs housed at lower densities, due either to decreased pig-to-pig contact or decreased stress. Alternatively, if the initial infection occurs at approximately the same time for all pigs in a barn, pigs that remain on the farm longer (because they were initially a lighter weight or grew more slowly and therefore were marketed later) had more time to recover from the infection prior to slaughter. Stocking density has known impacts on growth performance in swine,[78–81] but data regarding animal density and marketing group as risk factors for shedding of salmonellae are sparse. Linton et al[27] identified higher prevalence of infection in pens with higher pig density, but this result was not confirmed on subsequent sampling in the same herd. Morrow et al[82] also reported a lower isolation prevalence of salmonellae in cecal contents at slaughter in pigs in older marketing groups. Further investigation is needed to evaluate the effect of stocking density and marketing group on *Salmonella* prevalence in swine. Potential interventions might include altering stocking density in finisher units or segregation of different marketing groups at slaughter, according to the risk of *Salmonella* infection. It is also critical to evaluate the effect of timing of sampling in order to standardize the measurement of *Salmonella* prevalence for future research investigations, since the determination of a herd's *Salmonella* status may vary with the timing of sampling.

Herd health status

Several authors have described lower risk of *Salmonella* infection in herds considered to be of high health status, usually defined by membership in specific pathogen free programs or membership in quality assurance programs that verify that certain management practices are conducted.[51,71] There have also been reports that herds experiencing diarrhea outbreaks during the growing phase were at increased risk for *Salmonella* infection.[83] In French swine herds, the odds for finisher swine to shed salmonella in the feces were greater if the pigs were seropositive for *Lawsonia intracellularis* or porcine reproductive and respiratory syndrome virus.[34] In a study of US swine, groups of finisher pigs with high *Salmonella* prevalence were more likely than low prevalence groups to have above-median feed conversion rates.[22]

These associations of *Salmonella* prevalence with health status may reflect the overall expertise and management skills of the pork producer, and it is difficult to hypothesize an exact mechanism, since so many management factors may be different in high health herds compared to conventional herds. The promising aspect of these associations is that if management practices that allow for high health status designation on swine farms are also associated with decreased risk of *Salmonella* infection, there will be economic rewards for these producers due to improved production performance even if market benefits are not available for *Salmonella* control.

Implications

- The epidemiology of *Salmonella* infection on swine farms is complex, and further research regarding control measures is needed.
- Cost effectiveness of any intervention on the farm, or at any level of the "farm-to-fork" continuum, must be considered in order to optimally utilize resources for reduction of *Salmonella* contamination.

- Presently, the most practical recommendation for *Salmonella* control on swine farms is to implement "good management practices" for disease control.

Acknowledgement

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