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Risk factors associated with *Salmonella* on swine farms

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Abstract

This manuscript reviews on-farm risk factors that have been associated with the prevalence status of *Salmonella* in swine. *Salmonella* is the second most common etiological cause of bacterial human food borne illness in the US, and most cases can be attributed to contaminated food products. Reduction of human food borne 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.

Introduction

An estimated 1.5 million cases of non-typhoidal salmonellosis in humans occur yearly in the United States, and nearly all cases are food borne.[1] This tremendous burden on public health has led to reduction of human salmonellosis to be a key public health objective.[2] *Salmonella* is a ubiquitous organism, and the gastrointestinal tract of vertebrate animals is considered to be its biological niche. Although *Salmonella* infection can result in clinical disease, it has long been recognized that swine can be asymptomatic carriers of *Salmonella*.[3-12] The number of farms and pigs positive for *Salmonella* in the US has been estimated to range from 38.2-83%, and 6-24.6% respectively.[13,14]

Beyond the potential impact on domestic public health and market stability, contamination of pork products with *Salmonella* may put the ~ $112 million pork export market at risk.[15,16] With the coordination of "farm to table" *Salmonella* control programs by many European pork producers (among the U.S.'s 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 US, due to differences in production systems, industry structure, and regulatory organization.

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

The focus of this review is on those on-farm risk factors for *Salmonella* 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" (exposure during transport, lairrage, contamination of carcasses during slaughter, etc) are not included in this review for the main purposes of brevity and a focus on potential on-farm interventions. These risk factors may suggest areas for further investigation for *Salmonella* control on US swine farms.

Hygiene

Good hygiene has long been stressed as important for *Salmonella* control and although intuitively appealing, is a difficult area to evaluate in research investigations. In a previous review of the literature[20], good hygiene was identified as the most important risk factor for *Salmonella*. Unfortunately, this importance was often based on subjective assessment by the investigator (good vs. bad hygiene farms), with little indication of how hygiene was measured. The main dilemma lies in an objective measurement of "good hygiene" and what level or components of "good hygiene" are important for *Salmonella* control. Results of epidemiological investigations to date suggest not all practices traditionally consistent with good hygiene are associated with decreased *Salmonella* prevalence on farms; in fact, it appears that some (e.g. all-in, all-out pig flow) may increase *Salmonella* risk.

Swine farm personnel hygiene practices have been associated with decreased *Salmonella* risk for swine. 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. Farms that had areas where clothes and footwear could be changed prior to entry into pig areas were associated with reduced *Salmonella* seroprevalence in Danish market swine[21] but were not identified as being associated with *Salmonella* seroprevalence in Dutch herds.[23] It has also been reported that herds with relatively more humans on site daily were at increased risk having high *Salmonella* fecal shedding[22], suggesting that increased human traffic on farms increases the pigs' risk of infection. Whether personnel hygiene practices are directly related to *Salmonella* risk or whether they simply serve as a proxy measure of a pork producer's overall attitude about hygiene is unclear, but it does suggest that improved personnel hygiene may be an important intervention for *Salmonella*. The relatively small cost incurred may be offset by decreased transfer of other performance impairing pathogens.[24,25]

The type of flooring pigs are reared on has been evaluated in epidemiological investigations. The biological premise is that certain flooring types decrease pig contact with fecal material. Swine housed on fenestrated (concrete slats, etc.) flooring were found to have lower *Salmonella* prevalence than pigs housed on solid26 or flush-gutter flooring.[13,27]

Apart from the associations with improved personnel hygiene and flooring types, the association between improved hygiene and decreased *Salmonella* prevalence becomes more tenuous. Pigs housed on partially solid floors with high levels of fecal contamination (as a result of dunging on solid parts of the pen) were, surprisingly, less likely to be *Salmonella* positive based on fecal culture than pigs housed on floors with lesser amounts of fecal contamination.[28] Although it has been described that farms that had an area to change clothing and boots prior to entering or leaving the pig area in combination with all-in/all-out production were nearly three times less likely to be seropositive for *Salmonella*[21], others studies find that all-in/all-out production with cleaning between groups is associated with increased *Salmonella* prevalence. A study conducted by Bahnson et al.[26] reported that "good hygiene" in combination with all-in/all-out pig flow was associated with increased *Salmonella* seroprevalence. In agreement with Bahnson, Stege et al.[29] indicated that all-in/all-out flow as well as manure-free cleaning between groups of pigs was associated with increased *Salmonella* seroprevalence. In another investigation[23], pig herds in the Netherlands that were reared in production systems where barns were cleaned and disinfected between groups of pigs were at greater odds to have increased *Salmonella* seroprevalence than in herd where floors and buildings were just cleaned but no disinfectant was used.

It is uncertain why the association between management practices considered "good hygiene" related to cleaning and disinfection and pig flow practices that are well recognized as important for reduction of production impairing diseases in swine may not have similar effects on *Salmonella* prevalence.[30-32] Contamination of the resident environment of animal housing has been implicated in many studies as a source of *Salmonella* infection.[7,33-39] *Salmonella* is capable of surviving at least 6 years or more in the environment,[40,41] and the challenges of cleaning and disinfection of animal housing are well documented.[42-45] Substandard cleaning and disinfection may allow *Salmonella* to remain as a contaminant on floors detectable by culture.[46] Rough surfaced concrete was more likely to have high levels of residual contamination after cleaning and disinfection than smoother surfaces in swine housing.[44] Yet, terminal disinfection either through fogging or fine mist of formaldehyde has been demonstrated to decrease the *Salmonella* contamination in poultry houses.[43,45] Human health risks are associated with formaldehyde use and the benefits of its use as a disinfectant should be considered.

Another hypothesis regarding the unexpected associations between all-in/all-out production with between group cleaning and *Salmonella* prevalence is that cleaning and disinfection reduces the number of competing microorganisms in the environment, allowing residual *Salmonella* that may be resistant to the cleaning procedures to survive more readily. Support for this "competitive flora" theory comes from the poultry literature for *Salmonella* control. Investigators have demonstrated that poultry placed on used litter had lower *Salmonella* prevalence than those on new clean litter.[47-52] It is hypothesized that old litter is a hostile environment for *Salmonella* as a result of properties of used litter (water activity, pH or other chemical components) or that *Salmonella* does not compete well with the bacterial microflora in the used litter.

The paradox presented by hygiene as a risk factor for *Salmonella* will likely continue to be a challenge for epidemiological studies and design of on-farm interventions. Before recommending interventions to swine producers, it is necessary to fully investigate what interventions will be cost-effective.

Importance of sow-to-pig transmission

Many investigators have reported relatively high *Salmonella* prevalence in breeding gilts and sows.[46,53-57] 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 only been minimally addressed. Several authors have demonstrated that piglets can be infected early in life.[6,46,58] Efforts to use segregated early weaning to prevent sow to pig transmission has had mixed results and are likely to be at best farm specific in success.[59-61] It is paradoxical that that different *Salmonella* serotypes are often isolated from sows and their piglets,[46,58] which might be explained by sampling error, colostral protection, or differential infection efficiency for serotypes in different age pigs. Recent epidemiological surveys in Denmark[62] have suggested that pigs produced from sow herds with high *Salmonella* seroprevalence are at greater risk for isolation of *S. Typhimurium.*

More research is necessary to evaluate the importance of sow prevalence on the risk of *Salmonella* in her offspring. If the sow herd is identified as an important source of *Salmonella* for growing pigs, it has important implications for the breadth and costs of surveillance and control programs.

The risk posed to swine by other vertebrate species

Since all vertebrates are susceptible to being infected with *Salmonella*, contact with other 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.[46] Yet, many other researchers have found no association with the presence of domestic animals other than the target species and *Salmonella*.[23,45,63-65]

Domestic cats residing on swine farms have been found to be shedding *Salmonella*.[66] Pests (rodents, wild birds, and other wildlife species) have often been implicated as potential sources of *Salmonella* for swine. Several investigators have demonstrated that mice and rats on farms can be infected with *Salmonella* and often with the same serotypes as the domestic species investigated.[66-71] Many cross-sectional investigations have isolated *Salmonella* from free-living birds at prevalence rates from 0 to more than 50%.[72-76] There is circumstantial evidence that sea gulls were responsible for two *Salmonella* outbreaks in Scotland.[72,74] Birds near broiler houses have been found to shed *Salmonella* at relatively high frequencies.[76] Finisher pigs housed in facilities that did not exclude birds were at greater risk to be *Salmonella* positive at slaughter than those reared in bird-proof facilities.[77] Foxes near poultry farms have been identified as shedding Salmonella.[71]

There are sufficient economic benefits for pest control on farms external to *Salmonella* control (building damage and control of other diseases) that can off-set the costs of pest control that justifies these interventions and may also result in decreased *Salmonella* risk for swine.

Risks posed by invertebrate species

It has been recognized that flies[66,71] and beetles[71,77,78] (both mature and immature stages) can be vectors for *Salmonella*. In fact recent research suggests that the free living nematode *Caenorhabiditis elegans* can be persistently infected with Salmonella.[78] Although there have not been epidemiological investigations to discern the attributable risk associated with invertebrate species, it appears that they may at least serve as a potential reservoir and vector on farms.

Reference	Sample origin[1]	# of samples	# of herds/trucks/ mills sampled	% samples positive	% of herds/trucks/ mills positive
McChesney (1995) Animal protein products[79]	M	101	78	56.4	62.0
McChesney (1995) Vegetable protein products[79]	M	50	46	36.0	37.0
Baggesen et al (1997)[88]	M	5,434	NR3	1.6	NR
Davies and Wray (1997)[86]	M	3,075	9	15.1	100
Fedorka-Cray et al (1997)[80]	T	549	25	0.7	22.7
Harris et al (1997)[81]	F,S	1,264	30	2.8	46.7
Stege et al (1997)[29]	F	1350	135	10.02	25.2
Funk et al (2001)[46]	F	800	2	0.25	50
Lo Fo Wong (2001)[21]	F	1394	188	6.9	17.6

Table 1. Frequency of *Salmonella* isolation from swine feeds in selected reports. [1]F-samples from feeders in barns, M-samples from feed mills, S-samples from storage, T-feed samples and swabs of feed trucks. [2]Represents the mode for the proportion of feed samples positive per farm. [3]NR-Not reported

Risk factors associated with feed

Risk factors associated with feed can be divided into two major categories 1) feed as a source of *Salmonella* due to contamination or 2) 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 can be contaminated with *Salmonella* (Table 1).[9,46,79-81] It has been demonstrated in experimental settings that animals can become infected as a result of consuming *Salmonella* contaminated feed[82], and there is a recently reported clinical outbreak of salmonellosis in swine in which contaminated feed is the implicated source.[83] There is no doubt that appropriate process control and decontamination steps are needed during feed processing to reduce contamination of feedstuffs in order to avoid dissemination of contaminated feed to herds. Pelleting of feed has long been recommended as a means of decontaminating pig feeds.[84,85] But pelleting must be appropriately conducted in order to be successful, including preventing contamination, especially during pellet cooling.[86,87]

There is justification to question the relative importance of the role of contaminated feed in the epidemiology of *Salmonella* on swine farms. Most notably, *S. Typhimurium,* a *Salmonella* serotype often associated with food borne disease in humans is infrequently isolated from feeds.[29,46,81,88] In fact one reference that compared isolation of *Salmonella* from feed with prevalence in swine indicated that low seroprevalence herds were more likely to have *Salmonella* isolated from feed samples than high seroprevalence herds.[29] In a multi-country survey in Europe *Salmonella* was isolated from feedstuffs in 17.6% of herds and 6.9% of all samples.[21] Yet, the *Salmonella* serotypes isolated from the feeds were not the same serotypes isolated from pigs on those farms.

Feed components and physical structure: The dry, the fine and the pelleted

Epidemiological investigations, predominantly from Europe, have repeatedly demonstrated that feed composition and structure are associated with *Salmonella* prevalence. Among factors that have been identified are feeding wet vs. dry diets to pigs, acidified diets (feed and/or water), feed particle size, feed form (pelleted vs. meal diets), heat-treated vs. non-heat-treated feeds, as well as actual feed ingredients. Many investigators have reported that swine herds that fed dry vs. wet diets were at increased risk to have high *Salmonella* seroprevalence.[21,23,29,89-91] Yet US pigs fed from wet/dry feeders were at increased risk of being positive by lymph node culture.[77] 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.[90] In clinical trials of feeding wet fermented feeds to swine, the results have been mixed. Fermented liquid feed did not decrease the prevalence of *Salmonella* as compared to dry feed in a clinical trial on an English herd.[92]

Whey feeds and acidifiers

Feeding whey in diets is typically done using a liquid whey product and is often the liquid used in fermented feed. In 1987, van Schie[93] reported that swine farms that fed liquid whey as part of the diet had a lower prevalence of *Salmonella* than those farms that used water to moisten the feed. In another study[21], herds feeding whey were at decreased risk of being seropositive for *Salmonella* Investigators hypothesized that a component of this effect may be related to the acidic pH of whey.

Interventions using organic acids in order to decrease the pH (mimicking the effect of whey) of pig feedstuffs or water have had varied results in clinical intervention trials. Among those studies that suggested that organic acids may be efficacious, addition of organic acids (formic acid or a combination of formic and proprionic acids) either in feed or water in concert with other management changes, appeared to reduce *Salmonella* seroprevalence.[94] Lactic acid added to dry rations (either pelleted or meal based) reduced the isolation frequency of *Salmonella* from pooled pen samples in a naturally infected herd as compared to pigs fed these diets without lactic acid.[95]

Other researchers have not demonstrated the same level of success with organic acids. In an on-farm clinical trial on a herd that had a chronically high *Salmonella* prevalence, formic acid added to the water of finisher pigs had no effect on seroprevalence.[96] When organic acids (commercially prepared formic and proprionic blend) were added to dry feeds in herds already infected with *Salmonella* at the time of organic acid administration, it did not reduce the *Salmonella* seroprevalence or isolation frequency from feces.[97] Wingstrand et al.[98] were only able to reduce *Salmonella* prevalence in 1 of 2 trials by adding organic acids to dry feeds. Feed acidification did not alter the *Salmonella* prevalence in British herds in before and after comparisons of fecal isolation of *Salmonella*.[92] In a multinational epidemiological investigation of European herds there was no association identified between addition of organic acids to the diet and *Salmonella* seroprevalence.[21]

It is ambiguous whether organic acids are an efficacious intervention for *Salmonella* control on swine farms. At best, the current status suggests that it is of variable benefit, particularly if formic acid or a combination of formic and proprionic acids are used. The positive results demonstrated with lactic acid may suggest an area of promise. Although organic acids can 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 implementing fermented liquid feeding systems. Further evaluation of the effects of acidic pH and fermented feeds on *Salmonella* prevalence is needed to evaluate their effects within commercial production settings.

Pelleting of diets and particle size

Many 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.[21,29,99] As to the biological mechanism that might result in increased *Salmonella* prevalence in pigs fed pelleted feeds as compared to those fed meal feeds, investigators hypothesized that it may be a result of the smaller particle size, heat treatment, or the pelleted form. For finisher pigs, it appears that the pelleted form and the fineness of grind, (but not heat treatment), are associated with increased *Salmonella* prevalence.[100-101] Unfortunately, treatments that resulted in the best *Salmonella* protection were also the treatment with the poorest production performance (feed efficiency in particular). No effect on *Salmonella* prevalence was identified with feed form (pellet vs. meal) in nursery age pigs.[95] Nursery pigs produced from sow herds that were fed pellets were at increased risk for high fecal prevalence of *Salmonella*, and the finishers from these pellet fed sow herds were at increased risk of high seroprevalence.[62,102] However, no significant difference in *Salmonella* seroprevalence or fecal shedding in sows was found between those fed meal or pelleted diets.[103]

In efforts to identify a feed that will reduce *Salmonella* concentrations in finishers without the concurrent reduction in production performance as seen with meal feeds relative to pelleted diets, investigators have evaluated the effect of different ingredients in pelleted form on *Salmonella* prevalence. A pelleted feed containing 10% beet pellets and a meal-form wheat based feed both decreased *Salmonella* concentrations as compared to a pelleted wheat based ration, but the pigs fed the 10% beet pellets had the added advantage of having growth performance equivalent to that of pigs fed the standard wheat based pellet diet.[104] In another experimental investigation[105], different wheat to barley ratios in pelleted rations on *Salmonella* seroprevalence were compared. *Salmonella* seroprevalence decreased with increasing barley content in the feed, and production performance was not significantly different from the standard treatment pellet that contained 100% wheat.

Although the identification of candidate ingredients that can alter *Salmonella* seroprevalence while maintaining production performance is promising, there is still more data needed to evaluate optimal concentrations in the diets, as well as the consideration of the economic implications of these ingredients relative to those used in the US. There is a need to evaluate different ratios of the predominant cereal grains used in US swine feeds.

Environmental Temperature/Season

Groups of finisher pigs in North Carolina USA with high *Salmonella* prevalence were at greater odds to have been sampled in winter and spring (approximately late November through late June).[22] In the same study, pigs reared during periods of large variability in daily high temperature were at greater risk to be high prevalence.[22] These results are similar to others who reported increased seroprevalence during the Fall and Winter in Danish swine.[106] Baum et al.[107] conversely, found that US herds tested in summer and fall had higher seroprevalence—but different herds were represented in each season, so it may only represent herd differences as opposed to seasonal variation.

Cool weather ventilation is a compromise between maintaining adequate air exchange while conserving heat which may result in periods where 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 with *Salmonella* prevalence. What makes further evaluation of this risk factor promising is that there are production performance and pig health advantages to maintaining proper ventilation for swine buildings, which could help off-set extra costs associated with improvement in ventilation engineering and management.

Stocking density/marketing group effects

Groups of finisher pigs categorized as having high *Salmonella* prevalence were more likely to be stocked at higher pig densities (less space allowance per pig) at the time of sampling than low prevalence groups in a study of US swine.[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 how many pigs had been removed for marketing prior to sampling. One potential explanation for this finding is that transmission/shedding of *Salmonella* is reduced when pigs are 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 sold to market later) had more time to recover from the infection prior to slaughter. There are known impacts related to stocking density for growth performance in swine[108-111] but the data regarding animal density and marketing-group as risk factors for *Salmonella* shedding in swine are sparse. Linton et al.[33] 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.[112] also described that pigs in older marketing groups had a decreased isolation prevalence of *Salmonella* from cecal contents at slaughter. Conversely, Bahnson and Fedorka-Cray[113] reported that the last group sold from a batch of pigs was at greater risk of high prevalence based on lymph-node culture at slaughter. Further investigation is needed to evaluate the effect of stocking density and marketing group on *Salmonella* prevalence in swine. Potential interventions could include altering stocking density in finisher units or segregation of different marketing groups at slaughter according to *Salmonella* risk. 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 farm's *Salmonella* status can be altered based on timing of sampling.

Herd Health Status

Several authors have described decreased risk for *Salmonella* if the herd is considered to be of high health status, typically defined by membership in Specific Pathogen Free (SPF) Programs or membership in quality assurance programs that verify certain management practices are conducted.[62,89,90,102] There have also been reports that herds that have experienced diarrhea outbreaks during the growing phase were at increased risk for *Salmonella* infection.[91,114] Groups of finisher pigs with high *Salmonella* prevalence were more likely to have above median feed conversion rates as compared to low prevalence groups in a study of US swine.[22]

These associations 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 as compared to conventional herds. The promising aspect of these associations is that if management practices that allowed for high health status designation on swine farms were also associated with decreased *Salmonella* risk, economically there would be rewards for producers due to improved production performance if market benefits are not available for *Salmonella* control.

Summary

It is evident that the epidemiology of *Salmonella* on swine farms is complex and that research regarding *Salmonella* control on swine farms is still needed. This complexity, despite the body of effort described in this review, is going to require significant resources in order to further elucidate the epidemiology of *Salmonella* and the efficacy of proposed interventions on swine farms. Perhaps just as critical, evaluation of the cost effectiveness of any intervention on the farm, or at any level of the "farm to fork" continuum must also be considered in order to best utilize resources for the reduction of *Salmonella* contamination. Coordinated efforts throughout the pork chain will be critical to achieving reduced *Salmonella* contamination of pork.

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