SALMONELLA IN SWINE FEED AND FEED INGREDIENTS: A REVIEW

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Early Perspectives on *Salmonella* in Animal Feeds and Feed Ingredients

The presence of the salmonellae as contaminants of animal feeds and feed ingredients has been recognized for over 40 years. In his extensive review of *Salmonella* in poultry feeds, Williams (1981) traced the first reports of finding *Salmonella* in feed in the U.S. and Great Britain back to 1948. Attention was first focused on animal by-products used in feeds such as meat and bone meal, fishmeal, and meat scraps, when it was found that feed made from such products contaminated by *Salmonella* had the potential of introducing and spreading salmonellosis to domestic animals (Muller, 1952). As early as 1954, Denmark required that all imported meat and bone meal was to be resterilized before sale due to an association between the occurrence of *Salmonella* in poultry and the importation of large quantities of meat, bone, blood, and fish meal and bones (Muller, 1957). Vegetable products and finished feeds, both meal and pellets were soon found to harbor the bacteria as well (Grumbles and Flowers, 1961).

Studies reported on the detection of *Salmonella* in transport, handling and processing areas of animal feed production and other environmental sites (Pomeroy, 1958). *Salmonella*- free rendered feed ingredients were found to become recontaminated through poor handling and storage practices (Boyer et. al., 1958), and *Salmonella* was transmitted to chicks in feed contaminated by the feces of rodents (Wilson, 1948). Heat treatment was recommended to eliminate *Salmonella* from meat meal (Kovacs, 1959).

Edwards (1958) was credited with first recognizing that efforts to eliminate salmonellosis from domestic animals must take into consideration the continual seeding of the animals through contaminated feedstuffs. A direct relationship was made between infection in turkey poults and *Salmonella* organisms in commercial feed fed to the poults, when the same serotype was found in unopened bags of the feed (Boyer et al., 1958).

Studies Concerning Feed as a Source of *Salmonella* in Pigs

Newell et al. (1959) in Northern Ireland, cited three studies to suggest that "the various *Salmonella* organisms so frequently isolated from fish and bone meal used for pig feedingstuffs might be related to *Salmonella* infections in pigs." A study was designed to examine by culture: pigs at slaughter, pigs on the farms from where the slaughter pigs originated, and the feedingstuffs on those farms in order to discover if there was a "chain of infection from a *Salmonella* contaminated product used in pig meals to a food eaten by humans." On one farm the *Salmonella* serotypes found in fish meal and in pig fattening meal (*S. infantis* and *S. schwarzengrund*) were also found in pigs on the farm and pigs at slaughter. The authors commented on the difficulty of tracing *Salmonella* from a human case of salmonellosis back to the animals that consume feed and ultimately to the introduction of a batch of contaminated feedstuffs because of the time lag involved. Tracing the path of organisms forward from contaminated feedingstuffs to human food made from animal products was a more feasible course of action. In this study, *Salmonella* were isolated in much higher numbers from cecal contents than from cecal swabs at slaughter. The authors felt that this did not indicate that *Salmonella* infections found in slaughter pigs were due to cross contamination in the holding pens, because the percentage of positive rectal swabs taken from pigs at the farms (9%) was greater than that from cecal swabs (2%), but lower than cecal contents (23%) obtained at slaughter. However, Galton et al. (1954), believed a great deal of spread occurred in sale barns, during transportation, and in holding pens prior to slaughter. Their group found a higher proportion of cecal swabs to be positive than post mortem rectal swabs and thought contamination might have occurred from the dehairing process.

Smith (1960) reported on the effect of giving feed naturally contaminated with *Salmonella* to eight week old pigs from a herd deemed free of *Salmonella.* The diet, containing contaminated fishmeal (50 organisms/100 g.) and bonemeal (700 organisms/100g.) was fed for 50 days during which time postmortem samples from sacrificed pigs and rectal swabs from the remaining pigs were cultured for the presence of *Salmonella.* The organism was demonstrated in the rectum of one pig after four days on the feed but only in the mesenteric lymph nodes after that. *Salmonella* was not found from rectal swabs until day 14 of the experiment for a total of 19 of 134 specimans collected during the 50 days. None of the rectal swabs collected up to 20 days after the cessation of feeding the contaminated feed were positive for *Salmonella.* The pigs were exposed to at least 21 serotypes in this feed. No harmful effect was noticed in the pigs which corresponded to a previous finding by the author that a 12% isolation rate was found in healthy pigs at slaughter. The author concluded that the main danger of feeding such contaminated feed to pigs was the risk of exposure to humans through meat from these animals contaminated by alimentary contents at slaughter, and that this risk may be ameliorated by withdrawing, before slaughter, feed supplements likely to be contaminated, as none of the pigs became permanent fecal excreters. No *Salmonella* were found in the pigs' feces after they were removed from the contaminated feed.

A British survey of fecal samples from pigs originating from 344 farms over a two year period, found an isolation rate of 0 to 12 % (Heard et al., 1969). The serotypes isolated had been frequently found previously in animal feeds and the authors suggested that "new infections occur from time to time on the farms via the feed."

In a series of papers, Kampelmacher and co-workers in the Netherlands (Kamplmacher et al., 1965; Guinee et al., 1965; Kamplemacher et al., 1963) examined the incidence of *Salmonella* in pigs at slaughter, the effect of transport on such incidence, the correlation between *Salmonella* isolated during life and at slaughter, and the effect of rearing pigs on decontaminated feed. They concluded that piglets may become infected at a very early age ("piglet infection"), possibly from the sow, and that *Salmonella* persists in the mesenteric lymph nodes without being shed in the feces. They stated that feeding decontaminated feed might suppress a *Salmonella* infection acquired early in life.

They found that in pigs not transported before slaughter, *Salmonella* isolations from the feces before and after slaughter were the same and that duration of transportation did not cause an increase in fecal contamination, however, the number of positive fecal samples was larger after transportation. They found that 214 of 566 (37.8%) of normal slaughter pigs were positive for *Salmonella.*

An increase in isolation rates from cecal contents and rectal swabs after slaughter was found compared to that obtained from rectal swabs before slaughter, although they stated that a single fecal examination was of low value in assessing *Salmonella* status. They concluded that contamination via the feed, while allowing for the possibility of organisms multiplying in the trough and contaminated by rats at night, appeared to be the means by which apparently normal pigs at slaughter acquired *Salmonella* infections.

Williams and Newell (1967, 1968) cultured pigs before a four hour transport, after placing in a holding pen, and after 12 to 19 hour holding periods. The *Salmonella* serotypes in the feed being fed to the pigs was known. Only one of 491 rectal swabs taken before transport was positive for *Salmonella.* After transport up to 72% were positive, but that number fell to 0-6% after holding for 12-19 hours. They concluded that excretion of feed source *Salmonella* stopped completely during the overnight holding time and that the numbers of environmental types decreased sharply. The authors postulated that the stresses of transport, handling, crowding, cold, and lack of feed or water may have acted to trigger a non-excreting pig into becoming an excreter of the *Salmonella* organisms. Stress could have caused an evacuation of the caecum and rapid passage of fecal material, which might have accounted for the higher isolation rate after transport. As the pig adapted to the holding pen, stress was decreased and the numbers of *Salmonella* in the feces abated. They concluded that *Salmonella* from the slaughterhouse environment could infect pigs which would then excrete the organisms for a short time. These organisms could subsequently be demonstrated at slaughter thereby becoming a potential source of carcass contamination. The authors stated that "the primary source of contamination (at slaughter) is most probably the *Salmonella*-excreting pig which has consumed contaminated feed ingredients on its farm of origin."

Williams and Newell (1970) cultured pigs before and after transporting them in a truck for about four hours. All the rectal swabs taken from the pigs in their pens were negative, but after the transport, 6/20 or 30% were positive for *Salmonella*. *Salmonella* was also isolated from the truck which had previously been steam cleaned and disinfected. As *Salmonella* had been isolated from the feed ingredients, the authors concluded that feed source infection occurred on the farm but was not measurable in the undisturbed animal, and may be at numbers less than the infecting dose for the animals.

Niven (1961) stated that the serotypes isolated from animal by-products were not found to correlate with those of *Salmonella* isolated from animals consuming feed containing those by-products. Neither was there a high incidence in the feces of such animals, although at slaughter there was a high degree of *Salmonella* infection in the colon. However, in a study by Lee et al. (1972) in Great Britain, infection found at slaughter was thought to originate on the farm where fishmeal in the feed introduced and maintained the infection in a group of pigs. The same serotypes were found in the fishmeal, and in the pig feces on the farm and in the cecal contents of the pigs at slaughter.

Katsube et al. (1973) studied the distribution of *Salmonella* in the intestinal tact and lymph nodes of the pig and concluded that the cecum was the most important site to culture to detect carriers of the organism.

A Minnesota study (Tay et al., 1989) comparing isolation rates for *Salmonella* in the lymph nodes and cecal contents of pigs at slaughter reported that of 167 (84%) sows that were positive for *Salmonella* at slaughter, *Salmonella* were isolated from 131 mesenteric lymph nodes (66%) and 60 cecal contents (30%). Nine different serotypes were identified. The authors concluded that the *Salmonella* from lymph nodes and other tissues may represent past infection, rather than contamination at slaughter, and that cecal *Salmonella* are more likely related to farm exposure than to infection during transport and holding. The isolation from mesenteric lymph nodes of *Salmonella* from 54% of clinically normal pigs led to the opinion that incising these nodes at slaughter could contaminate the carcass.

Surveys of Animal Feed and Ingredients for *Salmonella*

Over the years, surveys have been conducted which reflect the occurrence of *Salmonella* in animal feeds and ingredients. Some early findings are listed in Table 1. Those surveys which contained information more particularly on swine feeds are discussed below.
An extensive survey by the USDA (Morehouse & Wedman, 1961) involving 5,712 samples of animal by-products and complete feeds in 31 states found that 718 or 12.57% were positive for *Salmonella*. Of these, complete feeds composed 1415 samples of which 71 or 15% were positive. About the same time, workers in Canada (Isa et al., 1963), sampled 281 feeds and feed ingredients and found 42 or 15% to be contaminated with *Salmonella*. Of 33 samples of pig feeds obtained, one was positive. While allowing that the significance of this incidence rate of *Salmonella* in feeds

was speculative, they concluded that production of feed ingredients free of *Salmonella* would appear to be possible.

A USDA survey in 1966 sought to determine the incidence of *Salmonella* in three of the most common finished feeds and their four major ingredients (Allred et al., 1967). A total of 12,770 samples were collected at feed mills in 26 states. Of 1567 samples of swine feed, 3.13 +/- 0.58% were positive for *Salmonella*. They indicated that "a reduction in *Salmonella* contamination of animal by-product ingredients and the pelleting of finished feeds would be the logical approach to lowering the *Salmonella* contamination rate in swine and poultry feed," while allowing that "feed transmission is only one of many modes of transmitting salmonellosis in the animal population."

Patterson (1972) in Northern Ireland conducted a survey of feeds and feed ingredients of animal and vegetable origin. Of 53 samples of pig meals and pellets 3 or 5.7% were positive. These 3 were unpelleted feed. He stated that a clear link exists between the feeding of contaminated feed and infection in livestock consuming the feed.

In 1993, the FDA conducted a survey of animal and plant protein processors and found that 56.4% of the animal and 36% of the vegetable protein products were positive (McChesney, at al, 1995). A report on an on-going survey of finished feed and primary meal ingredients by the FDA presented the results for 66 meals and 62 complete feeds. Sixteen percent of the complete feeds and 48% of the meals were positive for *Salmonella.* Of the animal meals, 82% were positive and 37% of the meals of vegetable origin. For the swine feeds, 3 of 15 samples (20%) were positive (Mc Chesney, 1995).

An on-farm survey of swine feed and feed ingredients collected from 30 farms in eight states showed that *Salmonella* were isolated from at least one feed or feed ingredients in 14 (47%) of the 30 farms surveyed. Of a total of 1264 samples, 36 (2.9%) were positive for *Salmonella.* Finding *Salmonella* in the feed had a statistically significant association with six herd characteristics surveyed, including lack of bird-proofing, using finisher feed prepared on the farm versus purchasing such feed, and housing pigs in facilities other than confinement in the growing, finishing, gestation, and breeding stages of production (Harris et al., 1996).

Table 1: Early surveys on *Salmonella* in animal feed and ingredients

Sample type	No. serotypes	No. pos./total	%	Reference
fishmeal	NA	5/40	12.5	Bischoff (1955)
fish, meat meal	22	NA	15.6	Bischoff and Rhode (1956)
fishmeal	11	9/16	56	Boring (1958)
vegetable conc.	17	42/910	4.4	Hauge and Bovre (1958)
animal by-products	28	37/200	18.5	Watkins et al. (1959)
meat scraps and feed ingredients	41	156/666	23.4	Pomeroy and Grady (1960)
feeds and ingredients	44	ingredients - 9 finished feeds - 2.8 pelleted - 0.3		British Public Health Service (1961)
cottonseed meal	NA	7/136	5.1	Grumbles and Flowers (1961)
animal feed	59	718/5712	12.6	Morehouse and Wedman (1961)
commercial feed	71	3/23	13	Niven (1961)
by-products	43	75/980	17.9	Pomeroy and Grady (1961)
animal feeds ingredients, renderings	NA NA	NA NA	23 50	Schotts et al. (1961)
by-products	10	56/436	12.8	Burr and Helmbolt (1962)
feed and constituents	NA	42/281	14.9	Isa et al. (1963)
meat meal feather meal fish meal	68	178/206 21/37 12/68	86 57 18	Williams et al. (1969)

NA = Not available

Control of Salmonellosis in Swine Feed

The USDA launched a *Salmonella* surveillence program in 1963, gathering information on the numbers and locations of isolations, sources and serotypes in order to increase understanding of the epidemiology of the organism. A report evaluating this program after 15 years concluded that "...the major source of the *Salmonella* problem in man derives from foods of animal origin especially poultry, beef, and pork. Repeated infections of animals occur on the farm in large part because of contamination of feed. Infection persits in some animals, and transmission occurs when animals are shipped to processing plants and are awaiting slaughter. Foods are often contaminated from carcasses and certain organs, especially intestinal contents and lymph nodes" (Gangarosa, 1978).

In 1969, the USDA (USDA Committee on *Salmonella*, 1969) issued a comprehensive report on *Salmonella* which included an overview of control measures for animal salmonellosis. The recommendations at that time were as follows:

- minimize *Salmonella* contamination of animal, poultry, and fish by-products intended for animal feed.
- extend the effort to all feed ingredients and blended feeds.
- emphasize the need for improving feeding and management programs at the producer level, e.g., control of free-flying birds, rodents, and other pests.

For swine producers:

- improve husbandry practices including use of concrete slabs for feeding and pen sanitation.
- design swine buildings and equipment so they can by easily cleaned and sanitized.
- develop breeding herds free of *Salmonella* and other specific pathogens.

Prior to slaughter:

- transportation vehicles must be designed so they can be cleaned and disinfected beween uses.
- holding pens at local and terminal markets should be so constructed that they can be easily cleaned and disinfected. *Salmonella* contamination of sources of feed and water should be minimized.

Because of the concern that food-producing animals most frequently became infected with *Salmonella* through the consumption of contaminated feed, a survey for *Salmonella* in animal feeds was done in 1966 (Allred, et al. 1967). Based on these findings (of 1567 samples of swine feed, 49 (3.1%) were positive), a cooperative State-Federal program for the rendering and fish industry was created. The purpose was to reduce the level of *Salmonella* in those animal protein products by identification of areas of contamination and institution of control programs on a voluntary basis. This program was terminated in 1972.

Each participating plant had developed a *Salmonella* control program and it was felt further progress would require authority by federal officials to enforce recommendations. Another reason given was "evidence was still lacking that would indicate the elimination of *Salmonella* from animals feed would have a significant impact on *Salmonella* contamination of red meat and poultry and on the incidence of the disease in man." They concluded that efforts to reduce zoonotic salmonellosis would be to improve sanitary conditions in slaughter plants, educate food handlers and consumers, and conduct more research to minimize bacterial contamination during and after slaughter (Wilson, 1978). The number one research goal of the future according to the 1978 National Salmonellosis Seminar was the need for an in-depth study of the best methods to produce and maintain *Salmonella*-free feeds (Williams, 1978).

Six years later, the International Symposium on *Salmonella* was summarized by the statement that it was time to take what is already known about *Salmonella* and, together with any new information in progress, implement the control measures and the available technologies demonstrated to reduce *Salmonella* contamination of animals and the food produced from them (Mussman, 1984).

Animal Feeds and the Risk Potential for Human Salmonellosis

Some workers have indicated that control might depend on the serotypes of *Salmonella* involved. "Studies of *Salmonella* outbreaks have demonstrated that in animals and humans, contaminated food and feed-stuffs of animal origin can be the source of infection. Researchers have suggested that the impact of these agents on human foodborne *Salmonella* infections should be decreased by controlling the twelve serotypes most frequently associated with human infection and disease, rather than to decrease the number of all *Salmonella* that can contact humans" (Snoeyenbos and Pomeroy, 1984).

A review by Newell and Williams (1971) on the control of *Salmonella* regarding feed concludes with the statement that *Salmonella* contamination of pig feeds occurred worldwide and was found most frequently in feed ingredients made from animal, poultry, or fish sources. They emphasized that along with sanitation and pest control, protein concentrates should be *Salmonella* free in order to control this organism on the farm.

Walker (1957) postulated that organic fertilizers made from human sludge, meat and bone meals, hoof and horn meal, blood meal, and fish meal contaminated with *Salmonella* might be responsible for indirect infection of humans through animals and vegetables. He found that 50 of 123 such samples (40%) were found to harbor *Salmonella.*

Williams (1975) reviewed the environmental aspects of salmonellosis and stated that "a great deal of evidence existed which indicates that *Salmonella* serotypes have a path of infection from animal feed to pigs to pork and then to man.

Salmonella Control in Feed and Ingredient Processing

Proper terminal heating of meat meal was found to eliminate *Salmonella* (Nape & Murphy, 1971). The primary source of recontamination within the rendering plant was stated to be dust (Hansen et al., 1962). Recontamination by rodents was considered to be the single most important factor (Wedman, 1961).

Recontamination after processing was concluded to be the source of *Salmonella* contamination in one study (Morehouse and Wedman, 1961). At that time the authors concluded that there was not definitive evidence to link organisms from by-products in feeds to specific field occurrences of salmonellosis but that this potential disease threat deserved further analysis. They believed recontamination of animal by-products by rodents, in particular, was the most important single factor accounting for the presence of *Salmonella*. Wild birds, dogs, other animals, humans and contamination from the re-use of feed sacks were also implicated. Fifty percent of environmental samples around rendering plants were contaminated with *Salmonella* and that finished rendered products become contaminated from the environment during the latter stages of processing (Magwood et al., 1965).

Vanderwal (1979) in the Netherlands experimented with decontamination procedures for feed. He found that pelleting under steam with proper temperature and moisture conditions would decontaminate feed as well as the addition of 0.9% formic acid. There was a reduced level of contamination of animals at slaughter and also improved weight gain and feed conversion with either method.

Edel and Kampelmacher (1976) in the Netherlands examined 7756 pigs over a one year period and found 22.3% to be positive for *Salmonella*. Farms which fed pelleted feed instead of meal showed fewer animals to be positive for *Salmonella* at slaughter (20.75 versus 23.7% and 12.9% versus 21%); and fewer serotypes were found on farms with pellet feeding.

Pelleting of finished feed resulted in a 80-90% reduction in mean counts of *Salmonella* due to the heat treatment involved (British Public Health Laboratory Service, 1961).

In England, Ghosh (1972) found that serotypes found in pigs on the farm and in the processing plant corresponded to those isolated from feed. Heat treated pelleting prevented the introduction of *Salmonella* to the pigs as demonstrated by the absence of new serotypes during a two year period.

In a survey of two integrated broiler firms, 60% of the meat and bone samples taken at feed mills were contaminated with *Salmonella,* and 35% of the mash feed samples were positive (Jones et al., 1991). Pelleting the feed was found to reduce the isolation rates by 82%.

In a study comparing the incidence rates of *Salmonella* in pigs and animal feeds in Denmark and England, the much lower rate found in Denmark was attributed to the requirement that imported and domestic feed ingredients of animal origin be sterilized. A narrower range of serotypes was also found in Denmark. This sterilization of animal origin ingredients was thought to reduce pig infections in Denmark with *Salmonella* serotypes other than *S. typhimurium.* (Skovgaard and Nielsen, 1972).

In a study in which an isolated new turkey breeding premise was maintained *Salmonella* free for four years, it was found that when eight isolates of *Salmonella* were subsequently isolated from the premises, five of them were first isolated from finished feed. The authors concluded that feed contamination was a primary source of infection for the herd (Zecca et al., 1977).

McCapes et al. (1991) concluded that the critical control points for feed production were:

- purchase *Salmonella*-free feed ingredients, maintain strict sanitary protocols for personnel, the mill environment, equipment, and transportation
- pasteurize feed after all ingredients have been mixed together
- exercise strict sanitary measures afterwards to protect the feed from becoming recontaminated

Chemical additives for incorporating into complete rations have been studied for many years, particularly for poultry feeds (Westerfield et al., 1970). A diet containing 0.25% formic acid resulted in the elimination of *Salmonella* carriage by growing chicks (Hinton et al., 1985). A mixture of formic and proprionic acids in the feed before contamination with *Salmonella* prevented the establishment of infection in chicks (Hinton and Linton, 1988).

Formic acid (0.5%) was found to reduce the rate of *Salmonella* isolations in hen feed and also decrease the incidence of infection in newly hatched chicks (Humphrey and Lanning, 1988). These organic acids, proprionic, formic and acetic, have been added to both finished feeds and feed ingredients. They were found to reduce the number of viable *Salmonella* in feed thereby controlling initial contamination and preventing recontamination during processing and transport. This reduction, however, might not be sufficient to decrease the number of viable organisms below the minimum infective dose for some *Salmonella*. They also may not have the expected bacteriocidal activity in heavily contaminated feed (Sesti, 1994). A Canadian Feed Industry Association (CFIA) brochure recommended the addition of 4% proprionic acid to single ingredients and mixed feeds. After testing for freedom from *Salmonella*, the ingredient or feed should be mixed or diluted so that the level of proprionic acid did not exceed 0.5% (Blackman et al., 1990). The addition of *Salmonella* inhibitors to feeds and ingredients was considered an adjunct to a *Salmonella* control program and not a substitution (Garland, 1994).

Acidity of the feed was thought to be a factor according to van Schie and Overgoor (1987) who found that *Salmonella* occurred in a lower percentage of farms which used whey as part of the feed mix (40%) than on farms using only water (80%). The number of samples which were positive for *Salmonella* on the farms using whey was 19.4% as opposed to 64.1% on the farms using water.

Gamma radiation also has been tried successfully to sterilize animal feeds (Snoeyenbos and Pomeroy, 1984)

Other Factors Regarding *Salmonella* Control in Feeds

Salmonella has been isolated from a number of animal species, including reptiles and insects, and the environment. In one study, wild animals, birds, and rodents were considered to be potential reservoirs for infection, but that the more probable scenario was that they were infected by the same means as the pigs; the feed (Newell and Williams, 1971).

Salmonella has been isolated from lesser meal worms, American cockroaches, and German cockroaches, which were considered to be mechanical carriers of the organism (Jones et al., 1991). Greenberg (1964) found that *Salmonella* persisted in flies from the maggot to the adult stages, and contaminated flies may transmit the organism for a distance of at least three miles.

Of 2103 environmental samples and 715 mice and rats collected from 10 poultry farms, 5.1% and 16.2% respectively were cultured positive for *Salmonella enteriditis*. *Salmonella enteriditis* was reported to persist in an infected mouse population for at least 10 months (Henzler & Opitz 1992).

A report from Yoshimura et al. (1980) examined *Salmonella* isolated from animal feed ingredients for their antibiotic sensitivity. Of 110 strains of 41 serotypes, the proportion of resistant strains was 1.8% and no correlation was found between the serotype and the antibiogram of any of the strains. They concluded that *Salmonella* encountered in feed ingredients may not always originate from animals, and that *Salmonella* in feed hardly play a role in the emergence of antibiotic resistance in strains of animal origin.

The seasonal incidence of *Salmonella* infection was reported by Currier et al. (1985), who found that the isolation of *Salmonella* from cecal contents of 874 pigs at slaughter in Texas did not vary with season, however, more different types of serotypes were isolated during the hot, dry summer and fall seasons as compared to the cooler, wetter, winter and spring season.

Occurrence and Control of *Salmonella*

Many other countries have reported on the occurrence of *Salmonella* in animal feedstuffs, and employ various means for its control.

Salmonella control has been on-going in Sweden since 1961. The frequency of occurrence of *Salmonella* in animals and feedstuffs has been reported every fifth year since 1949. All Swedish feed producing plants are checked for the presence of *Salmonella* in ingredients, complete feeds and dust samples (Malmqvist, 1995).

Their control program encompassed the following strategies:

- prevent *Salmonella* contamination in the production chain

- monitor critical points of this chain to avoid contamination with *Salmonella*
- motivate producers to participate by economic incentives
- ensure cooperation and compliance through legal means

Today, meat and poultry produced in Sweden are claimed to be *Salmonella*-free (Wierup, 1991).

Since 1976, Japan has conducted annual surveys of animal feed ingredients. In the period from 1976 to 1982, the incidence of *Salmonella* isolations has varied from 11 to 26% (Sato, 1984).

The *Salmonella* control program in Denmark involved mandatory testing of feed for the presence of *Salmonella* in all plants producing animal feed. Finished products as well as samples taken during production are analyzed, and those batches found to be contaminated must be re-sterilized (Bager et al., 1994). The most recent report available from Denmark indicated that only 0.8% of the 2330 samples of pig feed tested were positive for *Salmonella* (Zoonose-Nyt, 1995).

Serological screening using an LPS mix ELISA test has been adopted as a means to monitor Danish swine herds for the presence of *Salmonella* (Nielsen et al., 1995). Slaughter plants are monitored by the bacteriological sampling of fresh pork for the presence of *Salmonella.* The level of *Salmonella* contamination in fresh pork was reduced from 3% to 1% with the implementation of the control program.

A Dutch survey of poultry feeds and feed ingredients for 1990-1991 reported that 10% of the samples taken were positive for *Salmonella*, and that mash feeds were more frequently (21%) contaminated than pelleted feed (1.4%). They found that the serotypes isolated most frequently from the feed were not the same as those isolated from the flocks (Veldman et al., 1995).

Some feed and ingredient manufacturers in the U.S. have active programs for the reduction of *Salmonella* in their products. For 20 years the Menhaden fishmeal industry and the National Marine Fisheries Service have participated in a federal inspection program for fishmeal products (Committee on Feed Safety, USAHA, 1994). The National Grain and Feed Association (NGFA) has published quality assurance programs for their members as has the Animal Protein Producers Industry (APPI), which has 235 rendering plants participating in a *Salmonella* testing program. The number of plants participating is reported to be increasing for this voluntary program (Feedstuffs, 1995).

In 1990, the Center for Veterinary Medicine announced a goal of *Salmonella*-free feed and feed ingredients. Progress toward this goal was to be achieved initially by developing and implementing Hazard Analysis Critical Control Point (HACCP) plans for all areas of the feed industry (Mitchell and McChesney, 1991). As application of HACCP programs evolved, it was found that addressing those processing steps for which a safety hazard has not been identified or cannot eliminate or reduce the hazard were better addressed with a prerequisite program approach combined with HACCP (McChesney, 1995). These prerequisite programs would have application to those areas of feed manufacturing such as sanitation, and post-processing handling of product.

Summary

As food producing animals are ultimately consumed by humans, we must be concerned about what food the animals consume. The many years of research that have been devoted to dealing with *Salmonella* in animal production point to the fact that there is no quick easy way to eliminate contact by our food producing animals with this ubiquitous organism in their environment. Salmonellae occur in many places and are generally very hardy. Control efforts must encompass all those ecological niches from where *Salmonella* might arise in order to be effective. Progress can be made as has been shown particularly in Sweden and Denmark. Implementation of the research findings which exist concerning effective management and control measures must be encouraged. Ultimately, control of *Salmonella* will be an on-going long-term process requiring the dedicated efforts of all those involved in animal production for human food.

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