Nutritional strategies to combat *Salmonella* in mono-gastric food animal production

A. C. Berge and M. Wierup

animal / Volume 6 / Issue 04 / April 2012, pp 557 - 564
DOI: 10.1017/S1751731111002217, Published online: 17 November 2011

Link to this article: http://journals.cambridge.org/abstract_S1751731111002217

How to cite this article:

Request Permissions : Click here
Nutritional strategies to combat *Salmonella* in mono-gastric food animal production

A. C. Berge\(^1\) and M. Wierup\(^2\)

\(^1\)Department of Reproduction, Obstetrics and Herd Health, Unit for Veterinary Epidemiology, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium; \(^2\)Department of Biomedical Sciences and Veterinary Public Health, Swedish University of Agricultural Sciences, P.O. Box 7028; 750 07 Uppsala, Sweden

(Received 1 April 2011; Accepted 23 August 2011; First published online 17 November 2011)

Nutritional strategies to minimize *Salmonella* in food animal production are one of the key components in producing safer food. The current European approach is to use a farm-to-fork strategy, where each sector must implement measures to minimize and reduce *Salmonella* contamination. In the pre-harvest phase, this means that all available tools need to be used such as implementation of biosecurity measures, control of *Salmonella* infections in animals at the farm as well as in transport and trade, optimal housing and management including cleaning, disinfection procedures as well as efforts to achieve *Salmonella*-free feed production. This paper describes some nutritional strategies that could be used in farm control programmes in the major mono-gastric food production animals: poultry and pigs. Initially, it is important to prevent the introduction of *Salmonella* onto the farm through *Salmonella*-contaminated feed and this risk is reduced through heat treatment and the use of organic acids and their salts and formaldehyde. Microbiological sampling and monitoring for *Salmonella* in the feed mills is required to minimize the introduction of *Salmonella* via feed onto the farm. In addition, feed withdrawal may create a stressful situation in animals, resulting in an increase in *Salmonella* shedding. Physical feed characteristics such as coarse-ground meal to pigs can delay gastric emptying, thereby increasing the acidity of the gut and thus reducing the possible prevalence of *Salmonella*. Coarse-ground grains and access to litter have also been shown to decrease *Salmonella* shedding in poultry. The feed can also modify the gastro-intestinal tract microflora and influence the immune system, which can minimize *Salmonella* colonization and shedding. Feed additives, such as organic acids, short- and medium-chain fatty acids, probiotics, including competitive exclusion cultures, prebiotics and certain specific carbohydrates, such as mannan-based compounds, egg proteins, essential oils and bacteriophages, have the potential to reduce *Salmonella* levels when added to the feed. These nutritional strategies could be evaluated and used in farm control programmes.

**Keywords:** *Salmonella* control, nutrition, poultry, pigs, supplements

**Implications**

The control of *Salmonella* in food animal production is of high priority. The European Union approach includes pre-harvest controls in poultry and pig production. Nutritional interventions to modify the gastro-intestinal environment have been shown to be useful tools to reduce *Salmonella* shedding in live animals. The dynamic and multi-factorial nature of *Salmonella* infections and the varying *Salmonella* prevalence in various production systems make it difficult to predict the effects of nutritional interventions on the *Salmonella* status of animals. This review aims to provide the reader a brief overview of the current nutritional strategies to control *Salmonella* in poultry and pigs.

\(^1\) E-mail: anna.berge@ugent.be

**Introduction**

*Salmonella enterica* subspecies *enterica* (hereafter referred to as *Salmonella*) is a worldwide public health hazard and, despite extensive research and scientific knowledge, the bacterium continues to cause significant human morbidity and mortality, and increasing levels of antimicrobial resistance are causing concern (Boyle et al., 2007). The European Union (EU) has shown clear initiatives to take on the challenge of reducing *Salmonella* in food animal production (EU Regulation 2160/2003). Post-harvest measures, such as hygienic slaughtering, processing and storage routines, can minimize the risks of *Salmonella* to consumers but they have yet to result in a sufficient reduction in human salmonellosis cases. The EU Member States have a very diverse *Salmonella* situation, ranging from negligible levels and a non-acceptance policy for *Salmonella* in the food animal production to a high
prevalence with limited control measures in addition to those determined by the EU. The dominant serotypes of *Salmonella* vary between regions and countries. Most serotypes do not cause clinical disease in animals but are more of a public health concern.

The EU has enhanced the monitoring and control of *Salmonella* in food animal production and increasing focus has been placed on pre-harvest controls and surveillance. The *Salmonella* control programmes in poultry have proven effective in many countries and a reduction in human cases has been attributed to lower levels of *Salmonella* in layers and a reduced transmission to eggs (EFSA, 2010). EU countries are now also facing the challenge of minimizing *Salmonella* in pig production.

Good internal and external biosecurity measures are key components of *Salmonella* control programmes to avoid the introduction of *Salmonella* onto the farm or to reduce infection pressure when *Salmonella* is present. The importance of minimizing the introduction of *Salmonella* through the purchase of animals cannot be overemphasized and focus is placed on cleaning up the breeding herds. Hygienic measures should take into account animals, housing, management, cleaning and disinfection. Feed plays a significant role in the control of *Salmonella* on two levels. First, the feed may potentially be an important vector to introduce *Salmonella* onto the farm. Proper control programmes must, therefore, be in place at any feed manufacturing site, as well as on the farm to avoid ingestion of *Salmonella* by the animals. Second, when animals are exposed to *Salmonella* through feed and other sources, feed composition, texture and supplements can be used to additionally minimize the risk of colonization and shedding of *Salmonella*. This paper will present a non-exhaustive list of major examples of how feed and feed supplements can be tools to use in *Salmonella* control programmes.

The inclusion of feed additives for the control of *Salmonella* has yielded varying results and often the products and their inclusion rates have not been properly evaluated in clinical and field studies. One reason is that *Salmonella* culture methods have low sensitivity, although new strategies, such as real-time PCR methodology, are being developed (Malorny et al., 2008). Furthermore, the stochastic nature of *Salmonella* infections on farms makes it difficult to evaluate differences in intervention studies, especially if the studies are carried out in the field in regions where *Salmonella* frequently occurs in the production of that animal and the environment, as is the situation in most countries. Therefore, many strategies yield inconsistent results across studies and clinical trial results often cannot be directly transferred to practical use on farm. The purpose of this review is not to provide an extensive and all-inclusive list of publications on the subject but to aid the reader to see the overall nutritional-related strategies that can be considered in a *Salmonella* control programme.

**Control of *Salmonella* in feed**

*Salmonella* is frequently found in feed ingredients, especially protein-rich feed sources (Wierup and Häggblom, 2010). *Salmonella* may also be found in compounded feed and even in heat-treated and pelleted feed due to environmental contamination of feed mills and the high likelihood for cross contamination in the feed mill and during transport and storage at the farm (Binter et al., 2011; Jones, 2011). The difficulties in sampling and culturing *Salmonella* from feed sources may lead to an underestimation of this risk (Davies and Wales, 2010). Many studies indicate and have shown that contaminated feed is a risk for the introduction of *Salmonella* onto the farm (Davies et al., 2004; Molla et al., 2010). However, the role of contaminated animal feed as a risk for human salmonellosis from an individual farm may vary depending on many production systems and management approaches (Marin et al., 2011; Torres et al., 2011).

Heat treatment, usually during conditioning, pelleting or extrusion, has been shown to be an effective way to reduce microbial loads in feed materials and compound feed. Different studies have verified the *Salmonella*-reducing effect of heat treatment (Himathongkham et al., 1996). Heating between 80°C and 85°C for 1 min in most cases should eliminate *Salmonella* (Jones and Richardson, 2004). However, the elimination is dependent on the level of contamination (Himathongkham et al., 1996) and the set temperature and time range may not be reached in all parts of the feed. Heat treatment for more than 30 s at more than 75°C can achieve a 1000-fold (3 log) reduction of *Salmonella*. Acidification can be used to decrease the risk of introducing *Salmonella*-contaminated feed ingredients into feed mills (Wierup and Häggblom, 2010). Organic acids have varying capacity to inactivate *Salmonella* in feed and it should be noted that they may also mask the presence of viable *Salmonella* that have not been completely inactivated by the acid treatment. The best efficacy results and lowest masking were achieved for a formaldehyde-containing product (Carrique-Mas et al., 2007). A thorough review of the use of various chemicals to reduce *Salmonella* contamination of feed contamination has recently been published (Wales et al., 2010).

**Nutritional *Salmonella* control strategies**

Nutritional *Salmonella* intervention methods can be carried out via general diet formulation or feed additives. Through diet formulation, the availability of fermentable substrate and buffering capacity can be influenced. The enteric microbial population is highly influenced by diet, and any dietary change is likely to influence the microbial flora. A number of feed additives have gained commercial acceptance in helping to reduce *Salmonella*. The list of EU-approved additives according to Regulation EC No. 1831/2003 is continually being modified (European Commission, 2011).

**Feed deprivation effects**

*Poultry*. Egg producers sometimes induce a moult in older hens to improve productivity and decrease mortality of hens compared with non-moulted hens of the same age. The most
common method is feed restriction for 10 to 14 days, combined with a reduction in the light period. It has been shown that moulting of layer hens can result in increased Salmonella shedding. Moulting hens in a Salmonella-infected flock may lead to an increased dissemination of the microbe as well as an increase in the number of Salmonella-contaminated eggs laid (Ricke, 2003; Golden et al., 2008). Feed withdrawal changes the crop environment, resulting in an increased pH and decreased concentrations of lactate, glucose and amino acids compared with non-moulted birds. The first environment that Salmonella encounters when ingested is the crop and the crop environment can, therefore, influence the survival and virulence of Salmonella not only in the crop but also in the distal part of the intestinal tract. Studies were carried out comparing moulting hens with non-moulting hens that were experimentally infected with Salmonella Enteritidis. The moulted birds had greater SCFA (Van Immerseel et al., 2006). The use of organic acids in feedstuffs and the highest in minerals. These acids are often added at a 0.5% to 3% inclusion rate depending on the buffering capacity of the feed and the acid. Acid-buffering capacity is the lowest in cereals and cereal by-products, higher in protein feedstuffs and the highest in minerals. These acids are often coated or encapsulated to protect them until they reach the lower intestine, where they are effective. Medium-chain fatty acids (MCFA), such as caproic, caprylic and capric acid, may have greater antibacterial properties against Salmonella than SCFA (Van Immerseel et al., 2006). The use of organic acids in feed and water may benefit overall animal performance through improved gut health.

Poultry. MCFA, caproic, caprylic and capric acid, were evaluated for the control of S. Enteritidis in chickens. The results suggested that MCFA decrease the ability of Salmonella to invade epithelial cells, resulting in a reduction in the numbers of bacteria in vivo (Van Immerseel et al., 2004).

Pigs. The reductions in Salmonella infection through the addition of various acids have not been consistent (O’Connor et al., 2008). Belgian research teams have been active in trying to find an acid to control Salmonella in pig production. A study evaluated four SCFA (formic acid, acetic acid, propionic acid and butyric acid) and two MCFA (caproic and caprylic acid) in vitro and in vivo in pigs experimentally infected with Salmonella. Coated butyric acid decreased Salmonella levels in pig caecal content, whereas uncoated acids did not (Boyen et al., 2008). Another in vitro laboratory study simulating the porcine caecum evaluated the influence of sodium caprate, sodium caprylate and sodium caprinate on Salmonella growth. The study indicated that Salmonella could be inhibited by caprylate. It was concluded that caprylate, in the form of encapsulated beads or as tricaprylglycerol oil, might have potential as a Salmonella-reducing additive in pig feed (Messens et al., 2010). A Belgian study (four herds, 600 pigs) investigated the effect of acidifying the water before slaughter. Treatment groups received acidified drinking water (pH = 3.6 to 4.0) and the control group received non-treated water (pH = 7.8 to 8.5) within 2 weeks before slaughter. The strategic application of a mixture of organic acids (formic, propionic, acetic and sorbic acid) in water during the last 2 weeks before slaughter did not seem to reduce Salmonella shedding and contamination of pigs shortly before and during slaughter (De Busser et al., 2009).

Physical properties of feed
The physical properties of feed greatly influence the passage and absorption of nutrients in the digestive tract and have been shown to influence Salmonella colonization and shedding in both poultry and pigs.

Poultry. Salmonella colonization in poultry may be influenced by grain type and particle size. A study was carried out investigating feeding coarse compared with fine-ground corn–soyabean meal and coarse ground with whole triticale–soyabean meal in broilers housed in cages and on litter (Santos et al., 2008). Feeding the whole or coarsely ground grains decreased caecal Salmonella populations in the 42-day-old broilers.

Pigs. The physical properties of feed have been shown to influence the susceptibility of pigs to Salmonella. Several epidemiological studies have identified that different forms of feed are associated with Salmonella prevalence in the herd. It is important to distinguish between the different forms of feed that may be included in these studies. Pelleting of pig feed is mainly carried out to improve feed conversion and not as a Salmonella control measure as it is in poultry production. In the wet feeding practice, the feed ingredients
are simply mixed in water and distributed through tubes by pumps and the feed pH is almost neutral. Producers may include food industry by-products in the wet feeding system that may slightly reduce the pH, such as whey. Wet feed should not be confused with fermented wet feed, in which the wet feed after supplementation by selected lactic acid bacteria is allowed to ferment under controlled conditions, resulting in a feed with a pH < 4.

Studies in the Netherlands have indicated that liquid feed containing fermented by-products was associated with a decreased risk of *Salmonella* infection in the farms (van der Wolf et al., 1999 and 2001). A French prospective study of 105 farrow-to-finish farms showed that the risk of *Salmonella* shedding at the end of the fattening period was increased when dry feed (v. wet feed) was provided during the fattening period (Belœil et al., 2004). Factors associated with pig herds testing *Salmonella* sero-positive (using the *Salmonella* mix ELISA tests) were evaluated in a study conducted in 359 finishing-pig herds in Germany, Denmark, Greece, the Netherlands and Sweden between 1996 and 1998 (Lo Fo Wong et al., 2004). Pigs fed non-pelleted feed (dry or wet) had 2 and 2.5 times lower odds of being sero-positive, compared with pigs fed pelleted feed. The protective effect of non-pelleted feed over pelleted feed was attributed to the structure and composition. The study also indicated that pigs fed whey (to drink or as the liquid part of the diet) had 2.6 times lower odds of testing sero-positive than pigs not receiving whey. Similar findings were reported in an European Food Safety Authority study of breeding pigs conducted in 2008, where feed of commercial compound origin or pelleted feed were found to be risk factors for *Salmonella* in faecal samples in farms using liquid feeding systems (Farzan et al., 2006). The same research team evaluated the risk factors for *Salmonella* in 80 representative swine farms and *Salmonella* was more likely to be found in farms where pigs were fed pelleted feed compared with mash or liquid feed (Farzan et al., 2010). The decreased levels of *Salmonella* shedding in wet feeding farms included in these studies may be partly attributed to the acidic form of the feed.

In some countries in Europe, coarse-ground meal is added to the diet of swine in herds with a high rate of *Salmonella* contamination. The intended effect is to decrease a too rapid passage through the stomach in pelleted fed pigs to allow the gastric acidification time to act and decrease the level of orally ingested *Salmonella*, usually from faecal contamination from pen mates (EFSA, 2008). Coarsely ground meal feed to pigs is believed to alter the physicochemical and microbial properties of content in the stomach, which decreases the survival of *Salmonella* during passage through the stomach. Coarse-ground meal, fine-ground meal, fine-pelleted meal and coarse-pelleted meal were compared in a study (Mikkelsen et al., 2004). Stomach contents from pigs fed the coarse-ground non-pelleted diet showed increased in *vitro* death rate of *Salmonella Typhimurium* DT12. Another study evaluated *Salmonella* attachments in the intestines of pigs fed different diet forms. Using a pig intestine organ culture model, *Salmonella* adhered 60% less (P < 0.05) to the ileal tissue of pigs fed the non-pelleted diets than to those fed pelleted diets (Hedemann et al., 2005; Farzan et al., 2006). However, the study confirmed findings from previous studies indicating that the feed conversion was more efficient in pigs fed the pelleted diets compared with non-pelleted diets. The role of the physical properties of pig feed is, however, subject to debate and a meta-analysis of 44 studies from 1950 to 2005 (O’Connor et al., 2008) concluded that ‘there should be a low level of comfort among qualified scientists that the claimed association between non-pelleted feed and reduced *Salmonella* prevalence is scientifically valid’.

**Probiotics**

Probiotics have been defined as ‘live-microorganisms which, when administered in adequate amounts, confer a health benefit on the host’ (FAO/WHO, 2001). A challenge with probiotic supplements is to verify the bacterial composition of the product and this presents challenges for market approval in the EU. The current probiotics in the EU are approved based on improved animal digestive health and performance. There is a long list of probiotic products licensed in the EU as ‘gut flora stabilizers’ for different animals and production categories (European Commission, 2011). Another challenge is to achieve probiotics that are not destroyed by pelleting, and are shelf-stable and cost-effective. A large variety of *Bacillus* spores have been investigated with regard to their stability and heat tolerance. Several commercial spore-forming *Bacillus* cultures have been shown to reduce food-borne pathogens and ameliorate intestinal health in various species. The challenge is, however, to find a cost-effective method to achieving sufficient concentrations of spores in the feed (Hong et al., 2005).

**Poultry.** Lactic acid bacteria cultures have been extensively researched for their ability to reduce *Salmonella* infection in poultry. They have been used commercially for *Salmonella* control in poultry and turkey production in many countries (Higgins et al., 2007 and 2010). The effect of the yeast, *Saccharomyces boulardii*, was evaluated experimentally in the 1990s. Broilers were gavaged with *Salmonella Typhimurium* and *Campylobacter jejuni* and the frequency of *Salmonella caecal* colonization was significantly reduced from 70% in non-supplemented control birds to 20% and 5% in birds fed a diet containing 1 g or 100 g dried *S. boulardii* kg feed, respectively (Line et al., 1998). In a further experiment evaluating *S. boulardii’s* ability to reduce populations of *Salmonella* and *Campylobacter* in broiler chickens subjected to transport stress, it was similarly found that yeast treatment significantly reduced the frequency of *Salmonella* colonization to lower than the pre-stress (before transport) levels, whereas non-supplemented birds had higher levels of *Salmonella* colonization (Line et al., 1997).
Pigs. Probiotics approved for pigs include Bacillus sp., Lactobacillus sp., Lactococcus sp., Bifidobacteria sp., Pediococcus sp., Enterococcus sp. and Saccharomyces sp. (European Commission, 2011). Common products in pig feed are Bacillus spore probiotics that have good heat-stability, preserving their efficacy during feed processing. Other common probiotic species are usually included at higher rates in the pre-processed feed to take into account their lower heat tolerance. Isolation and characterization of anti-Salmonella lactic acid bacteria from the porcine gastro-intestinal tract has been carried out to find probiotics that survive in gastro-intestinal passage (Casey et al., 2004). Lactic acid-producing probiotics have been shown to lead to an amelioration of diarrhoea in Salmonella Typhimurium-infected pigs early in the course of infection and reduced Salmonella counts over a longer time frame (Casey et al., 2007). A Salmonella infection trial in pigs evaluated the addition of anaerobically fermented yeast products (Saccharomyces cerevisiae) to the starter diet in weaned pigs following a challenge with 10^9 cfu of Salmonella Typhimurium DT104. The pigs receiving the yeast supplement showed slightly better BW gains post-infection than non-supplemented controls but the supplemented group had a tendency towards increased Salmonella shedding (Price et al., 2010).

Competitive exclusion (CE)

CE cultures are a form of probiotic culture that is only administered as a single dose. The CE culture is usually administered to the neonatal animal, such as the day-old chick or a newborn piglet, and it can also be used to restore the digestive tract flora after antimicrobial treatment. It is usually composed of a mixture of non-pathogenic bacteria typically found in the gastro-intestinal tract of the animal.

Poultry. CE was initially developed and used in poultry production, where newly hatched chicks can be protected from subsequent Salmonella infections by accelerating the establishment of a complex, protective microflora (Nurmi et al., 1992; Schneitz et al., 1992). Chicks hatched in sterile incubators are not normally colonized by intestinal flora compared with chicks hatched naturally under the hen in a nest containing faecal microbes. It is essential that the CE be administered before exposure to Salmonella. The Salmonella-preventing effect is also shown in field situations (Wierup et al., 1992), and the concept is now applied with a demonstrated effect also on other intestinal disorders (Schneitz et al., 1992) and intestinal pathogens. There are several commercial CE cultures on the market also with efficacy against Campylobacter (Stern et al., 2001) and Clostridium perfringens (Kaldhusdal et al., 2001). The search for improved CE cultures with efficacy to both Salmonella and Campylobacter is on-going and a relatively recent study indicated that cultures from free-range chickens on family farms provided better CE cultures than commercial farm chickens (Zhang et al., 2007). Furthermore, in the study by Santos et al. (2008), broilers housed in cages were compared with those housed on litter. Broilers raised on litter had lower caecal Salmonella populations than the caged birds and it is speculated that this could have been due to the fact that litter intake may have modulated the intestinal microflora by increasing competitive exclusion microorganisms, which discouraged Salmonella colonization. A European multinational study also indicated lower Salmonella levels in floor-raised layers compared with caged layers (Van Hoorebeke et al., 2010). These findings have been used as an excuse for not removing manure or cleaning and disinfecting between batches of broilers. Instead, the manure is removed only once a year, when it is also sometimes recycled. In addition, bedding is often home to Salmonella-contaminated rodents (Henzler and Opitz, 1992). Using this production method, it is practically impossible to reach European Salmonella targets for reduction (Mead et al., 2010).

Pigs. A mucosal CE culture from swine (MCES) was produced from the caecum of a 6-week-old pig (Fedorka-Cray et al., 1999) and administered to piglets within 6 h post-farrowing while a second group of piglets remained unsupplemented. The two groups were challenged with Salmonella cholerasuis 24 h post-farrowing. Seven days later, the pigs that received the MCES showed a 2- to 5-log_{10} reduction in Salmonella in the caecal contents or ileocaecal junction digesta compared with the controls. Administration of CE cultures to neonatal piglets has further been shown to reduce S. choleraesuis faecal shedding in pigs and pigs in contact with those that received the CE culture during the pre-weaning and the weaning period (Genovese et al., 2003).

Glycans

Carbohydrates (glycans) have long been known to be an important dietary component, seen predominantly as energy-yielding molecules and structural components of plant materials. A number of carbohydrates (based on glucose, mannose, galactose and fructose) have been shown to have anti-infective properties. Mannose and its polymers are the most commonly used products as feed additives and have been shown to reduce Salmonella colonization in chickens (Oyofo et al., 1989). The large majority of Salmonella contain mannose-specific lectins (Type 1 fimbriae) on the bacterial surface that bind to glycoproteins (rich in mannose) on the intestinal surface. Mannose sugars can thus compete with the intestinal glycoproteins for attachment sites and prevent colonization. Similar findings have been demonstrated with mannann oligosaccharide (MOS; Bio-Mos, Alltech Inc., Nicholasville, Kentucky, USA) at significantly lower concentrations than that required for purified mannose (Spring et al., 2000). In a series of three trials in which 3-day-old chicks were orally challenged with 10^6 cfu S. Typhimurium, birds receiving 4000 ppm of dietary MOS showed a 1.4 log (more than a 10-fold) reduction in caecal Salmonella concentrations 1 week later. In another series of three trials with Salmonella Dublin as challenge bacteria, the number of birds that tested Salmonella positive 1 week later was significantly reduced in birds fed MOS (90% v. 56%, respectively) (Spring et al., 2000).
Prebiotics
These are non-digestible food or feed ingredients that beneficially affect the host by selectively stimulating the growth and/or the activity of one or a limited number of bacteria in the colon, thus improving host health (Gibson et al., 2005). The prebiotic effect has been shown to not only influence the microbial composition of the gut but also to influence the immune system (Roberfroid et al., 2010). Prebiotics are mainly medium- to long-chain carbohydrates called oligosaccharides (also known as soluble fibre) but can also be proteins, peptides and some types of lipids. These prebiotics feed probiotics or commensal enteric bacteria, offering them a competitive advantage over potential pathogens, such as Salmonella. However, some studies with fructo-oligosaccharides and inulin indicate that there may be increased colonization with Salmonella using these products (Ten Bruggencate et al., 2004).

Egg proteins
Experiments have indicated that egg components included in feed to layers reduced Salmonella colonization in the birds. Feed containing 5.0% (wt/wt) of non-immunized egg yolk powder was shown to eliminate an experimental challenge infection with S. Enteritidis and also prevent S. Enteritidis colonization in laying hens, with no adverse effects (Kassaify and Mine, 2004a). Another experiment using experimental infection with S. Typhimurium indicated that a 10% egg yolk inclusion in the feed eliminated the infection and lower doses decreased infection (Kassaify and Mine, 2004b). The Salmonella reduction properties of the egg yolk were investigated and attributed to the anti-adhesive properties of the egg yolk granule component, high-density lipoproteins (Kassaify et al., 2005). Egg yolks from hens hyper-immunized against Salmonella have also been shown to decrease Salmonella shedding in chicks (Rahimi et al., 2007).

Essential oils
A range of essential oils have been shown to have bacteriostatic or bactericidal properties against Salmonella in vitro (Burt, 2004). Citrus essential oils have been screened by a disc diffusion assay for their antibacterial action against 11 serovars of Salmonella and it was concluded that these oils have the potential to be used in organic and natural foods (O’Bryan et al., 2008). Another study indicated that basil oil has the potential to reduce the growth of Salmonella in food (Rattanachaikunsopon and Phumkhachorn, 2010). Studies are currently lacking regarding the applicability as a Salmonella intervention in feed.

Bacteriophages
Bacteriophages are viruses that can infect bacteria and these bacteriophages can be found in the gut of food animals. These are currently being investigated as a potential intervention strategy to reduce Salmonella levels in the live animal. Clinical studies have indicated that anti-Salmonella phages isolated from faeces from commercial swine have the ability to reduce caecal populations and faecal shedding in weaned pigs (Callaway et al., 2011).

Conclusion
There are numerous feed additives with the potential to control Salmonella in the pre-harvest phase of pork and poultry production. The challenge with nutritional interventions for Salmonella control is that the results are highly variable and dependent on the management, nutrition and Salmonella status of the farm. The numerous scenarios for Salmonella contamination of poultry and pig production species make generalizations difficult. Producers need to assess the tools available and evaluate them in their own situation. It is important to thoroughly investigate claims for Salmonella reduction and specifically note in vitro, in vivo and field trials. The current situation indicates that nutritional interventions should be seen as an additional tool in a systems-based approach to decrease Salmonella prevalence in all components of the farm system.

Acknowledgements
This review is based on an invited presentation at the 61st Annual Meeting of the European Association for Animal Production held in Hereaklion, Greece, August 2010. It has been funded by Berge Veterinary Consulting, Vollezele, Belgium, and Alltech Inc., Lexington, Kentucky, USA. The authors are grateful to Helen Warren for reviewing the language.

References
Davies PR, Scott HH, Funk JA, Fedorka-Cray PJ and Jones FT 2004. The role of contaminated feed in the epidemiology and control of Salmonella enterica in pork production. Foodborne Pathogens and Disease 1, 202–215.


