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Review article

A REVIEW OF POSSIBILITIES FOR CONTROL OF *Salmonella* AND OTHER PATHOGENIC BACTERIA IN PIG FEED

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ABSTRACT: Each category of pigs is susceptible to diseases caused by pathogenic bacteria, which negatively reflects on animal health, farm production results or meat quality. Animal feed is one of the potential reservoirs of pathogenic bacteria and infection source of domestic animals. *Salmonella* spp. is major microbiological hazard in animal feed. Thus, there is importance for implementation of strategies for preventing feed contamination with *Salmonella*, by minimizing dust, maximizing hygiene of space and processing equipment in feed mills and implementing control measures in each stage of feed production. Existing *Salmonella* feed contamination can be eliminated by conditioning and later different heat treatments (pelleting, extrusion, expansion) in production process while changing physical structure of the feed (coarsely or finely ground mash or pellets) can influence on conditions for *Salmonella* development in gastrointestinal tract of pigs. Contamination of feed by pathogenic bacteria and conditions for their development can be also controlled by addition of acidifiers, prebiotics, probiotics and, more recently, essential oils of plant origin, into feed. Various strategies for prevention of feed bacterial contamination, processes for feed decontamination, as well as possibilities for controlling pathogenic bacteria, especially *Salmonella*, in pig feed were presented and discussed in this article.

Key words: *pig feed, pathogenic bacteria, Salmonella, contamination*

INTRODUCTION

According to EFSA (2008) *Salmonella* spp. was pointed out as the major hazard for microbial contamination of animal feed, followed by *Listeria monocytogenes, Echerichia coli* O157:H7, and *Clostridium sp.* Between 15 and 20% of *Salmonella* infections in humans are caused by contaminated pig meat (Jansen et al., 2007). Oil seed meals and animal derived protein are major sources of *Salmonella* contamination of animal feed (Wierup, 2013). Regulation 2160/2003 of the EU outlined the need for developing proper measures for detection and control of *Salmonella* at all stages of production (EFSA, 2008).

Concerning that feed can be contaminated with *Salmonella* which can cause animal contamination, it is very important to include strategies for prevention of contamination and recontamination of feed and to eliminate existing contamination (Arguello et al., 2012). In this respect, some countries even prescribed mandatory programs for control of *Salmonella,* e.g. heat treatments (Sauli et al., 2005). Additionally, *Salmonella* can be controlled by differrent feeding strategies, i.e. physical structure of feed (coarse or fine, mash or pelleted). These strategies create unfavorable conditions for *Salmonella* within the gastrointestinal tract of pigs, while at the same time growth of normal bacterial microbial flora is promoted. Beneficial microflora prevents *Salmonella* growth by lowering pH of the digesta and/or by producing anti-*Salmonella* compounds and metabolites (Arguello et al., 2012).

Contaminated feed and newly purchased pigs are the most significant sources of infection in pig breeding. The weaning pigs are production category that is most often infected by *Salmonella*, which usually causes disease. On the other hand, adult pigs are also susceptible to infection but rarely show clinical signs and thus can enter slaughtering process which results in contaminated meat (Sauli et al., 2005).

All feed ingredients can be a potential source of *Salmonella*. For this reason, decontamination steps are important to prevent spreading of contaminated feed to animals. Different decontamination procedures are applied in practice, e.g. heat treatments (Maciorowski et al., 2007), the use of organic acids (Papenbrock et al., 2005) or other chemical preservatives (Rouse et al., 1988).

SALMONELLA IN FEED MILLS

Animal feeds (complete diets and single feedstuffs), if contaminated by *Salmonella,* are important source of contamination in animals (Sanchez et al., 2002). An issue related to control of *Salmonella* presence in feed is lack of uniformity of its distribution throughout the material. Consequently, several hundreds of samples are sometimes necessary to determine contamination level accurately (Jones and Richardson, 2004). Need to analyze high amount of samples for *Salmonella* contamination and high expenses of testing make sampling difficult (Jones, 2011). According to Mitchell and McChesney (1991) at least 30 samples must be analyzed to reliably determine if the given batch of feed is *Salmonella* negative. For this reason, it could be recommendable to use indirect indicators of *Salmonella* presence, such as *Enterobacteriaceae,* concerning that *Salmonella* belongs to *Enterobacteriaceae* family (Jones and Richardson, 2004; Vukmirović et al., 2013). *Enterobacteriaceae* counts higher than 10^4 cfu/g in unprocessed feeds and higher than 10^2 cfu/g in processed feeds may be indicators of *Salmonella* presence (Jones and Richardson, 2004).

Dust is the most important source of *Salmonella* contamination within the feed mill (Butcher and Miles, 1995). For this reason it is very important to control dust in feed mills from the very beginning of the feed production, i.e. from the unloading process where the largest quantity of dust is produced (Jones, 2011). Additional points of dust formation that must be controlled within the feed mills are grinders, mixers, elevator legs, conveyers, pellet scalpers (McDaniel, 2005). Morita et al. (2006) indicated feed mill operators as the main contamination conduit and outlined that it is important to designate areas within the plant as dirty and clean and to limit the flow of personnel, equipment and air in-between these areas. Fats protect *Salmonella* from environmental and physical stresses and it is hard to eliminate *Salmonella* from the areas containing fat accumulation (Morita et al., 2006; D’Aoust, 2007). Reduction of fat accumulation in the mill will decrease *Salmonella* survival and spreading (Jones, 2011). Additional vectors for spreading of *Salmonella* and other pathogen bacteria are rodents (Morita et al., 2006) and birds, and control measures regarding this must be implementted (Jones, 2011).

Area of receiving raw ingredients can be pointed out as area of the heaviest *Salmonella* contamination, therefore control efforts should be especially focused in this part of feed plant (Jones, 2011). Additionally, poorly designed or maintained grinding systems may result in intensive heat emission during grinding action causing moisture present in the material to migrate and concentrate, resulting in condensation. This will create favorable conditions for microorganism proliferation (Jones, 2008). An interesting survey of *Salmonella* presence in different parts of feed mill by Shrimpton (1989) indicated feedstuffs of animal origin, mixer and pellet conditioner as the points with the highest occurrence of *Salmonella*.

Multiplication of bacteria in processing equipment has been considered the major source of *Salmonella* in feed. At critical temperature and moisture conditions, multiplication of bacteria can occur in certain regions of a feed mill creating a major point of feed contamination. Consequently, adequate measures and processing procedures must be applied and become routine in feed manufacturing (Ziggers, 2003). Without adequate control measures, *Salmonella* can become endemic in a feed mill and extremely difficult to eradicate due to formation of biofilms on the surfaces of the equipment (Davies and Wales, 2010).

HYDROTHERMAL TREATMENTS

Feed ingredients can be contaminated in feed mills, transport vehicles or during feed storage (Kidd et al., 2002). If *Salmonella* and other pathogen microorganisms are present in feed ingredients, multiplication can occur during storage. The most commonly used method for prevention of microbial growth in feed components and compound feed is drying (Binter et al., 2011). Control of moisture content within the feed mill is essential for *Salmonella* control. Drying of cereal grains to moisture content 13-14%, and drying of oil seeds to 7-9% effectively prevents microbial proliferation. Moisture content of pig feed formulas is usually between 7.5 and 14% resulting in water activity level (expressed as Aw value) between 0.40 and 0.65 which inhibits microorganism growth (Eisenberg, 2007). Regarding *Salmonella,* keeping the Aw values bellow 0.94 will prevent its growth (Bell and Kyriakides, 2002). *Salmonella* can survive for long periods in dry material, and will multiply rapidly in presence of moisture. Consequently, it is very important to keep dry conditions in storage and in manufacture line (Sauli et al., 2005).

Salmonella is usually killed at temperatures higher than 55 °C but high concentrations of fat, starch and protein in feed form colloid layer that protect bacteria and increase its heat resistance. Consequently, temperatures higher than 80-85 °C are used in feed industry to achieve hygienisation effect (Hoh, 2010). Different heat treatments (pelleting, extrusion and expansion) can reduce *Salmonella* and other pathogen microorganisms in feed. The application of hydrothermal treatments (primarily steam conditioning and pelleting) is optional in pig feed production. The main reason for applying these processes is to prevent segregation of feed components, to increase digestibility, to hygienise the feed etc. (Binter et al., 2011). Even though hygienisation is not the primary reason for hydrothermal treatment of pig feed, it is also one of the important consequences of moist heat application. Hydrothermal treatments do not result in complete destruction of microorganisms in the feed (sterilization) but rather in pasteurization, i.e. in reduction of total germ count and in killing of all pathogen microorganisms (Kersten et al., 2005).

The pelleting process consists of conditioning (mixing steam and water with mash feed), pelleting (pressing conditioned material through die openings of the pellet press) and cooling (removing heat and moisture). Conditioning is considered as the most important phase of the pelleting process where combination of temperature, moisture and retention time reduces number of microorganisms in feed concurrently with preparing the mash for agglomeration in the pellet press. Temperature higher than 80 °C is necessary for elimination of *Salmonella* and other coliform bacteria during steam conditioning process while spore-forming bacteria can be resistant to pelleting temperatures higher than 90 °C (Veldman et al., 1995; Jones and Richardson, 2004). Conditioning is usually few seconds to several minutes (Thomas et al., 1997) but more recent constructions of conditioners enabled extending of conditioning time to enhance hygienisation of feed and improve product quality (Ziggers, 2003). Applying 80-85 °C for 30 min eliminated all *Enterobacteriaceae* from feed (Kampelmacher, 1981). When temperatures higher than 85 °C are applied for one minute during conditioning and pelleting, *Salmonella* should be completely eliminated (Veldman et al., 1995; Jones and Richardson, 2004). Besides temperature, decontamination efficiency of thermal treatments depends also of moisture content of feed and of treatment time. Destruction of *Salmonella* Enteritidis at temperature of 82.2 °C was increasing with increase of the residence time in the conditioner and with increasing the moisture content of feed (Himathongkham et al., 1996). Cover et al. (1985) suggested steam conditioning before pelleting at a temperature of at least 82.2 °C at a moisture level of 18%. In the research of Maciorowski et al. (2007), optimal temperature, time and moisture of feed conditioning process, in order to destroy *Salmonella* and *E.coli*, were 85.7 °C, 4.1 min and 14.5% feed moisture content.

Expanders and extruders could also be used in the production of pig feed, weather for processing of single feed stuffs or for processing of complete diets. Extruders and expanders are similar machines but expanders do not possess die with openings at the product exit and thus produce unshaped product. In the expanders, the moisture content, shear stress and production costs are lower compared to extrusion (Thomas et al., 1999; Prestløkken and Fôrutvikling, 2013). The extrusion and expansion processes are also known as HTST (high temperature and short time) processes, and during these processes generally higher temperatures and pressures are applied on the mash (Goodarzi Boroojeni et al., 2016) which results in more effective elimination of pathogen bacteria.

Thermal processed feed is at a great risk to be re-contaminated after thermal processing, i.e. during cooling, transportation, and storage, with the cooling step as a major point for recontamination. This is due to high amount of dust that is forming during cooling the agglomerated product with high air volumes. Dust collected from the coolers has greater contamination levels compared to dust from the other locations in the feed plant. Additionally, condensated water inside the cooler is another trigger for increased risk of re-contamination due to increased moisture level inside the cooler which creates favorable conditions for growth of *Salmonella* and other pathogen bacteria (Jones and Richardson, 2004; Jones, 2011). Organic acid inclusion is an option for prevention of feed recontamination with non-spore forming bacteria (Jones, 2011; Goodarzi Boroojeni et al., 2014). According to Maciorowski et al. (2004), combination of heat and acid treatment (e.g. propionic acid) is shown to be more effective compared to these treatments alone.

ESSENTIAL OILS

Since the use of antimicrobial growth promoters in pig feed has been banned in EU (regulation EC/1831/), essential oils have received increased attention as potential alternatives to in-feed antibiotics. They are plant secondary metabolites which contain complex mixture of volatile compounds with variable chemical compositions and concentrations (Li et al., 2012). It has been recognized that some essential oils can be used as antimicrobial agents because of their ability to control foodborne pathogens (Burt et al., 2004). It was also found that within the gastrointestinal tract, they provoke secretion of digestive enzymes and increase gastrointestinal tract motility (Westendarp, 2005).

It is difficult to make generalizations about the mode of action of essential oils on bacteria because essential oils contain different groups of chemical compounds, and hence, their antibacterial activity cannot be attributed to one specific mechanism. Mechanisms of action of essential oils on bacterial cell consider degradation of the cell wall, disintegration of membrane structure, leakage of ions and other cytoplasmic constituents, coagulation of cytoplasm, which leads to collapse of the proton motive force (Burt et al., 2004).

Essential oils with well-documented antimicrobial properties are those which contain phenolic compounds, such as carvacrol, thymol and eugenol, but also other substances such as cinnamaldehyde, thyme, phenylpropane, limonene, geraniol and citronellal (Borsoi et al., 2011; Franz et al., 2009). The antimicrobial activity of phenolic essential oils is ascribed to their delocalized electrons and the hydroxyl group on the phenolic ring (Burt et al., 2004). Thymol and carvacrol interact with the cell membrane by H bonding, causing the increased permeability of membranes and mitochondria, disintergration of the outer cell membrane and inhibition of the gram negative bacteria (Di Pasqua et al., 2007).

Essential oils demonstrated a certain degree of selectivity. It is generally believed that gram-negative bacteria are slightly less susceptible to the action of essential oils than gram-positive bacteria (Burt et al., 2004). When conducted in vitro test, Si et al. (2006) reported that essential oils showed a high inhibition toward pure cultures of *Salmonella*, with little effect on beneficial gut bacteria in mediums that consisted of pig cecal digesta. Ouwehand et al. (2010) found that the most effective essential oils at reducing growth of *Salmonella* were carvacrol, cinnamaldehyde, citral and thymol.

However, in an animal experiment which included piglets challenged with *Salmonella*, essential oils had no effect on the reduction of *Salmonella* shedding when added to the diet at the concentration close to their minimum bactericidal concentrations (Si et al., 2006b). The abolition of anti-microbial activity of essential oils after mixing with the diets was hypothesized to be the consequence of their binding to the feed particles (Si et al., 2006b). Oils which are generally hydrophobic, bound to the fats and other feed constitutes in pig diets, and thereby become unavailable to affect intestinal microbiota. In piglets, essential oils were showed to be absorbed almost completely in the stomach and the proximal part of small intestine within 2 h after oral administration (Michiels et al., 2008). In order to exert their anti-microbial activity in the pig's gastrointestinal tract, essential oils need to be protected. Micro-encapsulation of the oils before adding to the diet could be a valuable strategy to overcome this problem (Lallès et al., 2009).

Michiels et al. (2011) tested the addition of carvacrol and thymol into the piglet diet and found that these oils did not affect major bacteria of the pig foregut, but reduced the number of intra-epithelial lymphocytes and the ratio of villus height/crypt depth in the distal part of small intestine, indicating an improved gut health. The influence of thymol addition to a starter diet was analyzed in pigs with or without *Sallmonela* challenge (Trevisi et al., 2007). Thymol did not reduce faecal shedding of Salmonella, but it protected against a rise in body temperature 1-day post challenge. The final body weight after 29 days of experiment was not affected by thymol; however, feed intake was reduced. In a study of Manzanilla et al. (2004), piglets were fed a combination of essential oils with carvacrol and cinnamaldehyde together with capsaicin and reported an increased gastric retention time of ingested feed, which resulted in better nutrient absorption. Similarly, it was observed that essential oils could improve the activity of digestive enzymes and cause increased nutrient absorption, resulting in a better feed conversion ratio (Windisch et al., 2008). It was found that encapsulated essential oils containing thymol and cinnamaldehyde reduced the incidence of diarrhea by 50% and enhanced the immune status of newly weaned pigs. The addition of essential oils also improved the performance of piglets, resulting in greater growth rate and improved feed conversion rate (Li et al., 2012).

ACIDIFICATION

Addition of acids in animal feed, besides prevention of recontamination, has a supportive effect on the health of gastrointestinal tract of pigs and enhances nutrient digestibility. The addition of acids reduces pH and buffering capacity of the diet, reduces pH in the stomach which promotes digestion of proteins, promotes growth of beneficial bacteria and reduces growth of pathogenic bacteria in the intestines (Close, 2000). For the acidification of the pig feed, both inorganic and organic acids can be used. The inorganic acids possess only the effect of reducing pH value by releasing hydrogen ions (H^+), while organic acids, besides hydrogen ion, release an anion that has direct inhibitory effect on pathogen bacteria (Klausing and Riewenherm, 2010). Numerous research results proved that the inclusion of organic acids in pig diets reduces number of *Enterobacteria* in gastrointestinal tract (Canibe et al., 2005; Papenbrock et al., 2005; Kluge et al., 2006). Organic acid supplementation was initially introduced in feed for weaned piglets for prevention of post-weaning diarrhea and to improve growth performance in piglets (Sutton et al., 1991), but later it was observed that acidification also beneficially affects the performance of fattening pigs and sows. On the other hand, disadvantages of feed acidification are high costs per tonne of produced feed, corrosive action of acids and consequent damage of the equipment, and negative influence of acids on feed flavor which could decrease animal feed consumption (Ziggers, 2003).

Different organic acids display specific antimicrobial activities, e.g. lactic acid poses good antimicrobial activity, sorbic acid has an antimold effect, while formic and propionic acids shows both antibacterial and antifungal effect (Partanen and Mroz, 1999; Dibner and Buttin, 2002). The organic acids have been used for many years in commercial feed production mostly as feed preservatives. Formic and propionic acid are used most frequently but also lactic, citric, fumaric and sorbic acids and their salts serve as feed preservatives (Lückstädt and Mellor, 2011).The organic acids are usually used in the form of their sodium, potassium or calcium salts because salts are easier to handle due to their solid form, lower volatility, lesser corrosiveness and better solubility in water compared to free acids (Partanen and Mroz, 1999). The salts of the organic acids do not possess pH-reducing effect, only the antimicrobial effect. Additionally, these salts are good sources of minerals (Klausing and Riewenherm, 2010).

One of practical limitations of using the organic acids may be their prompt metabolism and/or absorption upon entering the duodenum. This can be overcome by using so-called encapsulated or protected organic acids. Microencapsulation enables protecting of active compounds, with protective matrix (i.e. fat coating) delaying the dissociation of active molecules in the stomach. In this way, organic acids will reach intestine where present enzymes will dissolve fat or other type of coating as it passes along the intestine and release the active compound (Piva et al., 2007; de Lange et al., 2010).

Reduction of acid binding capacity of feed has a similar effect as the acid addition. Acid binding capacity of feed can be reduced using different strategies, e.g. decreasing the calcium content to be <0.85%, the use of calcium formiate as a source of calcium, decreasing protein content below 18% with concurrent using of synthetic amino acids. Acid binding capacity can be reduced also by decreasing level of phosphorus below 0.45% while at the same time addition of phytase will secure phosphorus digestibility from plant phytate (Klausing and Riewenherm, 2010).

PHYSICAL STRUCTURE OF THE FEED

According to numerous research results, physical structure of pig feed, i.e. pelleted or not, coarsely or finely ground, has an important influence on Salmonella occurrence in gastrointestinal tract of pigs. Even though pelleting, as thermal treatment process, can reduce microbial contamination in compound feed, it has been well documented that non-pelleted feed has a protective effect against *Salmonella* compared to use of pelleted feed (Jørgensen et al., 1999; Rajic et al., 2007; García-Feliz et al., 2009). Similarly, coarsely ground mash has a protective effect compared to fine ground mash pig feed (Jørgensen et al., 1999; Jørgensen et al., 2001; Mikkelsen et al., 2004). Coarsely ground mash feed results in undamaged tissue of esophageal region in pigs' stomach, while both fine grinding and pelleting cause certain degree of tissue damage which sometimes led to gastric ulcers (Nielsen and Ingvartsen, 2000; Mikkelsen et al., 2004). If pigs are fed with coarsely ground feed, the passage rate in the stomach will be slower, dry matter content of the stomach increases, the number of total anaerobic bacteria is increased, concentration of different organic acids is increased resulting in lower pH value in the stomach. The slower gastric passage rate of pigs fed coarsely ground mash feed may result in higher microbial fermentation in the stomach as a consequence of increased time of bacteria to proliferate in the stomach. Coarsely ground mash feed creates physical conditions (more solid gastric content) in the stomach that stimulate growth of anaerobic bacteria. This results in increased production of organic acids and in low pH in the stomach that kills *E. Coli* and *Salmonella* (Mikkelsen et al., 2004; Klausing, 2010).

Even (uniform) acidification of digesta in the stomach is very important in respect to presence of pathogenic intestinal bacteria. *Salmonella* and *E. coli* have neutral to slightly alkaline pH optimum. The range of pH in pig's stomach is between 2 and 4 but it can be compromised by the amount and form of ingested feed (Klausing, 2010). Mash feed is consumed in smaller portions by the pigs during the day compared to the pelleted feed. Consequently, the quantity of feed in the stomach will be larger if the animals are fed pellets. Additionally, pellets require more time to dissolve which will all result in insufficient and uneven acidification of feed in the stomach (Klausing, 2011).

In some parts of digesta, pH may reach the value of 7 or more, which is ideal condition for *Salmonella* and *E. coli*. Uneven acidification of feed in stomach will cause fluctuating secretion of bicarbonates from pancreas into the duodenum which may result in pH value above 8 in duodenum and this creates optimal conditions for Gram-negative pathogenic bacteria (Klausing, 2010).

Combination of low pH and high concentration of lactic acid in the stomach reduced number of *Salmonella* entering small and large intestine in pigs (Mikkelsen et al., 2004). When pigs were fed coarse ground mash feed, *Salmonella* presence was significantly reduced compared to pigs fed pelleted feed (Jørgensen et al., 1999).

Using of coarse ground mash to produce pellets also reduced *Salmonella* presence in the pigs, but the level of detection was not as low as for pigs fed coarse ground mash feed. In the research of Mikkelsen et al. (2004), higher concentration of butyric acid was observed in ceca and colon of pigs fed coarsely ground feed, with butyric acid promoting epithelial cell growth.

PREBIOTICS AND PROBIOTICS

Probiotics are live microorganisms that, when administrated in a certain amount, exert beneficial health effects in the host animal by improving intestinal microbial balance (Callaway et al., 2010). Probiotics have been shown to stimulate the development of a healthy microbiota, inhibit the growth and dissemination of pathogenic microorganisms, improve gut tissue maturation, stimulate mucosal immunity, enhance digestive capacity and lower the pH in gastrointestinal tract of young piglets (de Lange et al., 2010). Most commonly used probiotics are members of lactic acid bacteria, particularly *Lactobacillus* and *Bifidobacterium* which are normally present in the gut. Administration of *Lactobacillus* and *Bifidobacterium*, immediately after birth, stimulates the growth of a beneficial microbiota capable of inhibiting colonization of enteric pathogens in premature neonatal piglets (Siggers et al., 2008). Collado et al. (2007) investigated in vitro protective effect of *Bifidobacterium* and *Lactobacillus* on the adhesion of pathogenic bacteria to swine intestinal mucosa. They revealed that the probiotics, alone or in combination, reduced the adherence of *Salmonella*. In combination, these probiotics enhanced each other's adhesion, mainly in large intestinal mucosa. The mixture of five strain probiotics mixture containing *Lactobacillus* and *Pediococcus* reduced pathogen shedding in weaned piglets challenged with *Salmonella*. The administered probiotic bacteria also reduced incidence, severity, and duration of diarrhea (Casey et al., 2007).

Probiotics *Enterococcus faecium and E. faecalis* are often utilized in clinical trials regardless they have not been proposed for the concept of Qualified Presumption of Safety by the European Union (EFSA, 2007). The supplementation of *E. faecium* to the feed of pregnant sows and piglets affected the early intestinal bacterial colonization of suckling piglets which is reflected in the reduced enteropathogenic bacterial load (Scharek et al., 2005).) Piglets treated with *Enterococcus faecalis* were less able to defend themselves against *Salmonella* infection, as showed by increased fecal excretion and colonization of *Salmonella* in organs. However, the probiotic treatment resulted in greater production of specific antibodies against *Salmonella* (Szabó et al., 2009).

Probiotic group called competitive exclusion involves the utilization of intestinal bacterial culture prepared from the gut content of the healthy adult animal (Gaggìa et al., 2010). Neonatal pigs treated with bacterial competitive-exclusion culture derived from the cecal contents of healthy pigs shed significantly lower pathogen numbers after challenge with *Salmonella,* and also showed reduced numbers of *Salmonella* bacteria in the gut (Genovese et al., 2003). Fedorka-Cray et al. (1999) observed reduced *Salmonella* counts in cecal contents and at the ileocolic junction in *Salmonella* challenged weaning piglets fed a competitive exclusion culture derived from the mucosa of healthy pigs.

Prebiotics are non-digestible food ingredients which beneficially affect the host by stimulating the growth health-promoting bacteria (mainly bifidobacteria and lactobacilli) in colon (Tanner et al., 2014). Commonly used prebiotics in animal feed are oligosaccharides with different molecular structure. It was reported that galactooligosaccharide mixture inhibited the adherence of *Salmonella* and *E. coli* to HT29 cells in vitro (Tzortzis et al., 2005). Addition of the mixture at 4% to a pigs' diet, increased the density of bifidobacteria and the acetate concentration, and decreased the pH value.

In comparison to probiotics, prebiotics are cheaper and easier to manipulate and include into diets. Symbiotic effect of prebiotics and probiotics can enhance the efficacy of probiotic effect on the health of gut microbiota (de Lange et al., 2010).

CONCLUSIONS

For controlling *Salmonella* and other pathogenic bacteria contamination in pig feed, prevention is first and much important step by assuring implementation of control measures in feed mills during all feed production stages. If the feed is inevitably contaminated, there is array of various techniques for feed decontamination such as thermal treatments, addition of acidifiers, prebiotics, probiotics and essential oils in feed, as well as feeding strategies by changing physical structures of feed in order to minimize animal infections. Selection of proper strategy for decontamination and prevention of recontamination depends on level of feed contamination, feed type, available process equipment and additives and costs.

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ПРЕГЛЕД МОГУЋНОСТИ ЗА КОНТРОЛУ *Salmonella* И ДРУГИХ ПАТОГЕНИХ БАКТЕРИЈА У ХРАНИ ЗА СВИЊЕ

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Сажетак: Свака категорија свиња склона је болестима које узрокују патогене бактерије што се негативно одражава на здравље животиња, производне резултате на фармама или квалитет меса. Храна за животиње представља један од потенцијалних резервоара патогених бактерија и извор инфекције домаћих животиња. *Salmonella* spp. је велика микробиолошка претња храни за животиње. Зато је важна имплементација стратегија за превенцију контаминације хранива салмонелом попут смањења настале прашине и побољшања хигијене простора и процесне опреме у фабрикама хране за животиње, као и испуњење контролних мера у свакој фази производње. Постојећа контаминације хране за животиње салмонелом може се елиминисати применом поступка кондиционирања и термичких процеса (пелетирања, екструдирања и експандовања) који обично следе у производњи, док се променом физичког облика хране за свиње (грубо или фино млевена смеса, пелетирана смеса) може утицати на услове за развој салмонеле у гастроинтестиналном тракту свиња. Контаминација хранива патогеним бактеријама такође може да се контролише додатком закисељивача, пребиотика, пробиотика, као и, у скорије време, етеричних уља у храну за свиње. У овом раду приказани су и продискутовани различити приступи за контролу, превенцију, и елиминисање контаминације патогеним бактеријама, са нарочитим акцентом на *Salmonella* spp.

Кључне речи: *храна за свиње, патогене бактерије, Salmonella, контаминација*

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