NUTRITIONAL STRATEGIES FOR THE PREVENTION OF COLIBACILOSIS IN YOUNG PIGS. EFFECTS ON IMMUNE RESPONSE, DIGESTIVE HEALTH, AND GROWTH

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1.- INTRODUCTION

Enteropathogenic E. coli (ETEC) strains are the major cause of gut infections, diarrhea and high animal mortality in commercial pig production. In particular, strains that produce F4 or F18 fimbriae cause high mortality in the post-weaning period (Fairbrother et al., 2005). At weaning, piglets are particularly vulnerable to infections, partly due to the sudden lapse of maternal immunoglobulins and other protective antimicrobial factors delivered through the sow’s milk (Lalles et al., 2007). In commercial farming, piglets are typically weaned at 4 weeks of age, when their immune system is not yet fully developed. Thus, the transition from milk by suckling to solid feed is a challenging phase that requires adaptations of the piglet’s metabolism, gut microflora and immune system.

Resistance to E. coli pathogens relies on many factors, including host related (genetics, age) and environmental (feed, housing, management) factors. How these factors interact to protect pigs and other mammals from gut infections is still not well understood, and animal models that allows understanding these complex interactions is critical for achieving essential knowledge. The main purpose of this paper is to give an overview of our current knowledge concerning the possibilities by use of nutritional strategies to prevent colibacilosis in young pigs.
2.- PATHOGENESIS OF PWD IN PIG

Diarrhea caused by ETEC has been reported as the most regular intestinal diseases with a great economical impact on the pig industry worldwide. Although pigs of all ages are susceptible to diarrhea, most outbreaks of ETEC-diarrhea occur during the first 2 weeks after weaning. This diarrhea is typically associated with faecal shedding of large number of β-haemolytic E. coli serotype that particularly proliferates in the small intestine of pigs (Fairbrother et al., 2005; Heo et al., 2013), and for this reason, PWD is sometimes called post-weaning colibacillosis. Yet, diarrhea due to ETEC in pigs after weaning is a multifactorial disease (Canibe and Jensen, 2012; Pluske, 2013). In addition to the presence of ETEC in the small intestine of piglets, weaning-related stress and weakened immune competence, weaning age, feeding regimen and the presence of other infectious agents are critical for the diarrhea to develop (Fairbrother et al., 2005). The ETEC causing diarrhea mostly carries the O149:F4 (K88) or O138:F18 fimbrial adhesion, which may mediate the adhesion to the specific receptors on the porcine small intestine enterocytes. This adhesion inflicts colonization of the intestine by ETEC, which in turn enable them to deliver enterotoxin such as heat labile toxins (LT) or heat stable toxins (ST, variants STa and STb). The LT toxins increase secretion of sodium, chloride and hydrogen carbonate ions into the lumen, whilst the ST toxins reduce the absorption of liquid and salt (Heo et al., 2013). This process eventuates in diarrhea (Figure 1).

The receptors for F4 do differ from the receptors for F18, suggesting that pigs susceptible to ETEC F4-diarrhea may not be susceptible to ETEC F18-diarrhea (Fairbrother et al., 2005). With regard to the susceptible pigs, they may be homo- or heterozygotic carriers of the gene encoding for the intestinal F4R or F18R. The pathogenicity of F18 depends on the presence of a receptor in the small intestinal mucosa of piglets and alpha-(1,2)-fucosyltransferase gene (FUT1) is the candidate gene controlling the adhesion to this F18 receptor. A guanine/adenine mutation at nucleotide 307 of FUT1 has been found resulting in pigs with genotype AA being resistant to F18 and pigs with genotype GG or AG being sensitive. Pigs susceptible to E. coli F18 show no difference between genotypes regarding spontaneous E. coli-PWD occurrence (Frydendahl et al., 2003). However, in a recent experiment we demonstrated that piglets with genotype GA were more susceptible to intestinal colonization with E. coli F18 ex vivo, and thus are probably more sensitive to E. coli F18-diarrhea, as compared to piglets with genotype AA (Sugiharto et al., 2015), and that the FUT1 genotype influences the gastrointestinal colonization of other bacterial groups than F18 (Poulsen et al., 2015). On the other hand, a study with homo- or heterozygous F4R+ and inoculation with E. coli F4 or not suggested that both F4 homo- and heterozygous susceptible pigs have similar functional receptors for E.coli F4, which facilitate the adhesion of F4 to the intestinal tissue (Sugiharto et al., 2012).
Figure 1.- Development of diarrhea in pig after weaning due to ETEC expressing F4 or F18 fimbriae (modified from Fairbrother et al., 2005 and Heo et al., 2013). Exogenous ETEC must pass through the stomach as the first line defense of the host before reaching the SI. Adherence of ETEC to the specific receptor on the SI-epithelium is prerequisite for the ETEC colonization and production of enterotoxin leading to diarrhea.

Figure 2.- Adhesion of ETEC to the porcine intestinal epithelial cells leading to diarrhea (modified from Roubos-van den Hil, 2010). Infection (diarrhea) develops only in pigs with the specific receptors on the porcine intestinal epithelial cells.
3.- THE INTESTINAL ECOSYSTEM AND DEFENCE OF PIGS

The intestine is a complex environment that makes up two equally important functions to support the life of the pig, i.e., the functions of digestion and the host defence [Pluske, 2013]. In general, there are three principal components that produce the complex ecosystem in the intestine, including intestinal epithelium, immune cells and commensal microbiota. To achieve a healthy function and activity of the intestine, the stable alliance of these components is required. The broken alliance as a result of the alterations of any of the components of the ecosystem may result in intestinal dysfunction and pathology.

3.1.- Intestinal Microbial Population

The intestine of pigs harbours various populations of microorganisms, which are characterized by a high total population density, a wide diversity and a high complexity of interactions (Lallès et al., 2007). The intestine contains both bacteria that are beneficial for the health, such as gram-positive lactobacilli and bifidobacteria, and potential pathogenic bacteria, such as E. coli. A number of intestinal disorders, including diarrhoea, have been associated with the shift in the composition, numbers or habitat of intestinal microbiota. Several factors have been reported to influence the balance of the intestinal microbiota of pigs, of which the change of the intestinal environment related to weaning is the major cause of the intestinal microbiota shift [Jensen , 1998], i.e., dysbacterosis. After weaning of the pig from the sow, several potentially favorable lactic acid bacteria (LAB) are significantly suppressed (Jensen et al., 1998), whereas the numbers of pathogenic bacteria increase in the intestine (Boudry et al., 2008). All these alterations may result in an increased susceptibility of the pigs to colonization of pathogenic bacteria.

3.2.- Intestinal Mucosal Immune System

The immune system protects the host against potential harmful substances by identifying and eliminating them. The porcine immune system comprises innate and adaptive immunity. The innate immunity is the first line of host defence against the invading organisms and is mediated by humoral factors such as complement proteins and cytokines as well as diverse cellular components including granulocytes (basophils, eosinophils and neutrophils), mast cells, macrophages, dendritic cells and natural killer (NK) cells. The adaptive immune system consists of two major cell types, the T and B lymphocytes, which in cooperation with antigens presenting cells (APC) such as macrophages, dendritic cells and B cells, enable specific recognition of and response to invading organisms. T lymphocytes are highly specialized cells that are responsible for cell-mediated immunity, whereas B lymphocytes are the major cell type involved in
humorally acquired immunity (antibody production). Microorganisms that invade the host are initially recognized by the innate immune system. Innate immune responses are, however, not always effective in eliminating the invasive pathogens because some microorganisms have developed the ability to avoid detection or clearance by the innate immune system. Viruses, bacteria and fungi have been reported to employ multiple strategies to avoid the host innate immune system (Akira et al., 2006). This condition may in turn lead phagocytes to activate the adaptive immune system to deal with these microorganisms.

The largest immune organ is located in the intestine where the mucosal immune system interacts with host and intestinal microbiota, playing an important role in protecting the host against potential harmful microorganisms (Burkey et al., 2009). Intestinal epithelial cells protect the host by providing the physical barrier and producing a variety of innate antimicrobial defences including mucins and several antimicrobial compounds, such as lysozyme and defensins. In addition to the epithelium, the intestinal immune system employs gut-associated lymphoid tissue (GALT) which tightly interacts with the intestinal epithelium (Burkey et al., 2009). The GALT is a highly organized immune compartment and constitutes the largest mass of immune cells in the body and is also a dominant site for the initiation of mucosal immune response (Dvorak et al., 2006).

The intestinal mucosal and systemic immune systems differ in many structural, cellular, molecular and functional ways. Mucosal tissues possess an innate and adaptive immune system that is largely independent of the systemic immune system. The GALT contains specialized immune cells such as intraepithelial T lymphocytes and antigen-presenting epithelial cells, which are not found elsewhere (Dvorak et al., 2006). Thus, the mucosal and systemic immune systems may differ in their response to pathogens invading the host. Another characteristic that may distinguish the intestinal mucosal immune system from the systemic counterpart is the capability of the intestinal immune system to be tolerant of the ubiquitous food antigens and normal microbiota while maintaining the ability to permit the absorption of nutrients (Burkey et al., 2009). This feature prevents unnecessary and detrimental inflammatory responses to the commensal microbiota and dietary nutrients (Dvorak et al., 2006).

3.3.- Intestinal Microbiota and Immune Interactions

The intestinal microbiota is an essential inducer of development and maturation of the intestinal immune system, and the induction of the immune system may depend on the type of microorganisms as well as on the time of colonization. The intestinal commensal microbiota is involved in host immune defense mechanisms, contributing to the protection
against invading enteric pathogens. Lactobacilli are a group of commensal bacteria that have long been known for their ability to activate the intestinal immune system and to increase the resistance to diseases, in part through the release of low-molecular-weight peptides which induce immune activation. These bacteria also produce a wide variety of short chain fatty acids (SCFAs) such as butyrate, propionate and acetate, which are essential for regulating cells of both the innate and adaptive immune system (Schuijt et al. 2013). In addition to that, the commensal microbiota in the gut has been reported to possess key functions, such as producing vitamins and fermenting complex fibres and proteins, which affect the intestinal mucosal barrier and immune response. Not only restricted to the local host intestine, the intestinal microbiota may also modulate immune responses at systemic sites, i.e. it has been suggested (Schuijt et al. 2013) that released bacterial metabolites and microbial components may be translocated from the intestine to the circulation, where they potentiate systemic immune responses against the invasion of pathogens.

4.- NUTRITIONAL IMMUNOLOGY

Nutritional immunology is an emerging discipline that evolved with the study of the detrimental effect of malnutrition of the immune system. While malnutrition still remains a worldwide problem among humans, life-stage and natural stress are increasingly becoming major causes of lowered immune status in both humans and animals. Weaning of the pig may lead to growth check, which can directly influence the immune status of the pig. Besides, the common weaning age occurs in an immunological gap, i.e., when the piglet is at its weakest immunological state, because the passive immunity serves by the sow through colostrum and milk is decreasing while the active immunity is not yet fully developed.

Nutrition is crucial for an adequate immune response, and malnutrition affects all mechanisms of defense (unspecific, cellular, and humoral immunity), and may lead to increased risk of infectious diseases. Almost all nutrients in the diet play a crucial role in maintaining an optimal immune status, and there are several mechanisms involved in immunomodulation: Substrates for the immune system (amino acids, trace minerals, water-soluble vitamins), modulation of signal transduction in leukocytes (polyunsaturated fatty acids, fat-soluble vitamins), influence on the hormonal milieu (ratio of protein and energy), influence of intestinal dynamics and microbial composition (fibre), protection against immunopathology (antioxidants), and some nutrients (e.g. iron) may nourish the pathogens (Klasing, 2007). Importantly, diets and nutrients nourish immune cells, modulate them and
facilitate establishment of commensal microflora, but diets should not normally stimulate the immune system.

**Figure 3.- Weaning takes place typically when the piglets are at its weakest immunological state**

Besides nutrition, there are several ‘non-nutritional’ components, which may have a direct influence on the immune system of the gut: Probiotics (such as lactic acid bacteria, various bacillus species and yeast) are defined as “live microorganisms which, when administered in adequate amounts, confer a health benefit on the host” (FAO/WHO, 2001), and can exclude pathogens, enhance intestinal barrier function, and positively modulate the immune system. Some carbohydrates (i.e., non-starch polysaccharides) may function as prebiotics, which are defined as non-digestible food ingredients that stimulate the growth and/or activity of bacteria in the digestive system in ways claimed to be beneficial to health.

**5.- DIETARY INTERVENTION TO CONTROL POST WEANING DIARRHOEA**

In response to the ban of antibiotics use in swine husbandry, attempts have been intensified for solutions to control PWD in pigs based on the nutritional concept (Boudry et al., 2008). Besides the importance of the feed intake immediately after weaning (Sørensen et al., 2009), it has been shown that feeding low protein diets may reduce the incidence of PWD in antibiotic-free piglets. Likewise for the human infants, attention has been given to nutritional immunology in order to minimize infectious diseases. Some foods or food ingredients have been suggested to contain factors that positively affect the humans or pigs in response to enteric infections and thus, can be alternatives to antibiotics (de Lange et al., 2010).
5.1.- Feed intake and dietary protein levels

The post-weaning period is characterised by an immediate, but transient, drop in feed intake. Sub-optimal intake of nutrients and energy can compromise both the efficiency of digestion and absorption and intestinal barrier function, which can consequently lead to increased susceptibility to pathogenic enteric conditions such as post weaning diarrhoea. Due to their immature digestive system, weaned piglets are dependent on highly digestible feed ingredients to ensure their healthy growth. The higher digestibility of ingredients in the weaning diet is associated with the greater nutrient intake, as well as less substrate available to pathogens in the hindgut (Kil et al., 2010). A challenge experiment with E. coli 0149 focusing on various dietary factors revealed that a feed intake of less than 200 g during the first day after weaning seemed to be associated with a relatively high incidence of a post weaning diarrhea-like condition (Sørensen et al., 2009). Thus, piglet performance may be improved if the piglets can achieve a daily feed intake of at least 200 g during the first day after weaning.

Besides cereals, protein is the major ingredient in weaning diets. Although high protein diet is associated with gastrointestinal tract hypertrophy (Pond et al., 1986) and thus probably essential for animal growth, feeding high protein diet for piglets around weaning could not be recommended as it may lead to a significant increase in the occurrence of PWD (Kil et al., 2010). At the common weaning age (3–4 weeks of age), the activity of the digestive enzymes especially in pancreatic tissue is low, and hence feeding high protein diet may cause protein malabsorption resulting in increased amounts of undigested crude protein (Hedemann and Jensen, 2004). The undigested protein may then enter the large intestine where it will be fermented by the resident microorganisms resulting in substrate for potentially harmful microorganisms. The undigested protein may also contribute to increased production of toxic nitrogenous compounds such as branched-chain fatty acids, indole, phenols, amonia and biogenic amines which are harmful for the intestine and provoke the development of PWD in piglets (Nyachoti et al., 2006, Opapeju et al., 2009). Hence, feeding low protein diets may reduce the incidence of PWD, however, this feeding strategy may compromise the growth of the piglets after weaning because of a reduced supply of essential amino acids.

5.2.- Supranutritional zinc levels

Feeding supplemental zinc (zinc oxide, ZnO) to weaned pigs at pharmacological levels up to 2,500 mg/kg, which is allowed in Denmark and Belgium, have been reported to ameliorate and/or prevent the development of PWD (Højberg et al., 2005), and hence could be a substitute for in-feed antibiotics. The mechanism through which zinc exert the
PWD-reducing effect has not yet been fully elucidated, but it may be due to the antimicrobial and immune-enhancing properties of zinc. According to Højberg et al. (2005), the effect of zinc resembles the working mechanism suggested for some in-feed antibiotics, i.e., the suppression of gram positive commensals (LAB) rather than potentially pathogenic gram-negative organisms (coliforms). This condition may therefore have long-term negative consequences on the immune functions of piglets (Hill et al, 2010). Janczyk et al. (2013) reported that feeding supplemental zinc (2,500 mg/kg) immediately after weaning could positively affect the immune responses of piglets infected with Salmonella typhimurium, but for a short period only. After two weeks, all positive effects disappeared and rather negative effects, such as lower T cell frequencies, occurred. A recent study showed an immediate effect of ZnO on E. coli induced diarrhea in pigs ranging from 3-4 days post weaning until 8-10 days after weaning (Vahjen et al., 2015). Environmental considerations should be taken into account when using zinc (or copper) at high levels, as this leads to heavy metal contamination of the soil (Fairbrother et al., 2005). Thus, supranutritional level of zinc is not a feasible alternative to in-feed antibiotics in piglets.

5.3.- Mechanisms of diarrhoea prevention

As described above, the gastrointestinal tract of a pig is a very complex environment, which undergoes rapid changes around the time of weaning. The changes have been divided into the acute phase (observed within the first 5-7 days after weaning) and the subsequent adaptive phase (Burrin and Stoll, 2003). The changes ascribed to the two phases were primarily based on the changes in feed intake and the subsequent impacts the enteral nutrition has on the gastrointestinal tract, because it takes 7-14 days for weaned pigs to learn how to eat and resume a level of dry matter intake (at least) that is comparable to that during the pre-weaning period (Pluske et al., 1997). If the gastrointestinal tract is deficient in macronutrients, micronutrients and energy, then its health, development and any subsequent recovery in the adaptive phase will be impaired. In addition, a given immune response towards colibacillosis may cost in terms of nutrient consumption. For example, a 30% reduction in hepatic vitamin E was observed in pigs after inoculation with E. coli post weaning (Lauridsen et al., 2011).

In general, the possible modes of action by which the nutrition or food components may prevent and/or reduce ETEC-diarrhea in pigs during the postweaning phase are:

1. preventing gut from ETEC adhesion and colonization
2. reducing the sensitivity of fimbrial receptors on the porcine enterocytes
3. blocking the fimbriae of ETEC
(4) inhibiting the growth of ETEC in the gut (due to bactericidal and/or bacteriostatic effect of food/food components)

(5) preserving the stable/balanced intestinal microflora between beneficial bacteria and potential pathogenic bacteria,

(6) improving the host immune functions (systemically and enterically)

(7) controlling the excessive inflammatory responses and

(8) preventing disruption of intestinal mucosal integrity and/or improving the morphology of the small intestine.

Table 1 shows examples of components which have been reported potential for ETEC-diarrhea prevention and/or reduction in pigs, and the possible mechanism by which the food component affected diarrhea incidence.

5.4.- Fatty acids and essential oils

The influence of lipids on immune responses is probably the most documented relation between nutrition and immunity. The amount and type of dietary fat can modulate immune function both at systemic and intestinal levels. Indeed, fatty acids are structural components of cell membranes and are signaling molecules and precursors of the synthesis of eicosanoids. Both excesses and deficiencies could be harmful to the immune system. Absorption of long-chain fatty acids enhances migration of T lymphocytes to Peyer’s patches. Fat absorption could also indirectly influence the mucosal immune system increasing cytokine release from intestinal epithelial cells. The profile of dietary fatty acids has an effect on the immune system.

The levels of polyunsaturated fatty acids of the omega-6 or omega-3 series seems of primary importance for immune modulation. The metabolism of the omega-6 and omega-3 series fatty acids is competitive because metabolic pathways of elongation or desaturation use the same set of enzymes. The major end-point of omega-6 and omega-3 pathways are, respectively, arachidonic acid and eicosapentaenoic acid. Arachidonic acid, from omega-6 fatty acids, leads to the production of pro-inflammatory eicosanoids. These proinflammatory molecules induce beneficial immune reactions, playing an immune-regulatory role, but can also lead to harmful reactions if they are mobilized to intensely, reducing the production of cytokines. Metabolism of omega3 fatty acids could counterbalance these negative effects by formation of eicosanoids less potent inducers of inflammation.
### Table 1.- Examples of feed components or feed additives that could potentially prevent and/or reduce ETEC-induced diarrhoea in piglets (modified after Sugiharto, 2014)

<table>
<thead>
<tr>
<th>Feed components or feed additives</th>
<th>Results on diarrhoea</th>
<th>Possible mechanisms through which food components prevented/reduced diarrhea.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicken egg-yolk antibodies</td>
<td>Reduced ETEC F18-diarrhea by 4× compared to pigs fed egg-yolk powder (containing no antibodies) Owusu-Asiedu et al. (2002)</td>
<td>Prevent gut from ETEC adhesion and colonization.</td>
</tr>
<tr>
<td>Dietary oligosaccharides</td>
<td>Reduced ETEC F4-diarrhea incidence by ±8% compared to pigs fed control diet (Liu et al., 2010)</td>
<td>Prevent gut from ETEC adhesion and colonization. Reduce the sensitivity of fimbrial receptors on the SI. Block the fimbriae of ETEC. Maintain balanced intestinal microflora. Improve host immune functions. Reduce cytokine-induced inflammation.</td>
</tr>
<tr>
<td>Probiotics</td>
<td>Reduced incidence of PWD in pigs (Manurung, 2012)</td>
<td>Hinder ETEC adhesion and colonization to gut. Produce substances and/or organic acids (especially lactic acids) possessing antibacterial effect. Lower the pH of stomach resulting less enterobacteria reaching the SI. Preserve balanced intestinal microflora. Improve host immune system.</td>
</tr>
<tr>
<td>β-glucan</td>
<td>Shortened the duration of PWD compared to control (3.4 vs. 4.3 days) (Stuyven et al., 2009)</td>
<td>Protect the SI from adhesion and colonization by ETEC. Improve host immune system.</td>
</tr>
<tr>
<td>Mannan</td>
<td>Reduced the incidence of diarrhea in weanling piglets compared to control (Zhao et al., 2012)</td>
<td>Prevent ETEC from binding to the gut wall and causing damage. Improve the immune system of piglets both systemically and enterically. Reduce cytokine-induced inflammation.</td>
</tr>
<tr>
<td>Organic acids</td>
<td>Alleviated the incidence of diarrhea postweaning (Tsiloyiannis et al., 2001)</td>
<td>Lower the pH of stomach (below 6) which prevents the entry of exogenous ETEC to the SI. Exhibit bactericidal and bacteriostatic effect which may prevent outgrowth of pathogenic bacteria (ETEC) in the SI. Stabilize gut microflora.</td>
</tr>
</tbody>
</table>
Provision of fish oil (rich in n-3 fatty acids) rather than sunflower oil (rich in n-6 fatty acids) inhibited inflammatory response of LPS-stimulated macrophages harvested from piglets post weaning (Møller and Lauridsen, 2006). In addition, the immune response was partially depressed in pigs fed a fish oil diet compared to pigs fed a corn diet than pigs were exposed to an E. coli LPS challenge (Liu et al., 2003). In addition, short- and medium chained fatty acids, phospholipids, and conjugated linoleic acid (CLA) may influence the host immune system, reduce cytokine-induced inflammation, and/or prevent disruption of intestinal mucosal integrity.

Essential oils, or aromatic plant essences, are volatile and fragrant substances with an oily consistency typically produced by plants. They have long been recognized for amongst others their antibacterial, antiviral and antioxidant properties (Bassole and Juliani, 2012). The strong antimicrobial activity of essential oils such as carvacrol and thymol, is attributed to their delocalized electrons and the presence of a hydroxyl on the phenolic ring. The oils initiate damage to the bacterial cell membrane, which compromises pH homeostasis and equilibrium of inorganic ions across the bacterial cell membrane. Moe inhibition have been observed towards gram negative than to gram positive bacteria, and some combinations, e.g. thymol with carvacrol and both components with eugenol) were synergistically active against E. coli strains. The challenge is that essential oils have been
found to be absorbed nearly completely in the stomach and the proximal small intestine within 2 h after oral administration (Michiels et al., 2008). Hence, essential oils need protection for delivery to the target site within the pig’s gastrointestinal tract to exert their anti-microbial activity, for instance by microencapsulation (Lange et al., 2010).

5.5.- Dairy products

There are other options available for producers to control development of diarrhea in pigs, and probably some food components may offer a cocktail of natural additives. It is apparent that colostrum, milk and milk fractions such as whey and casein contain several biologically active compounds with antimicrobial and immunomodulatory properties. Bovine colostrum contains high levels of immunoglobulins and growth factors such as IGF-1, and recently it was shown that provision of bovine colostrum rather than milk replacer to piglets after weaning reduced the colonization of the intestine by ETEC and modulated the intestinal immune system (Sugiharto et al., 2015), and freeze-dried defatted bovine colostrum reduced diarrheal episode in pigs postweaning (Huguet et al., 2012). Other dairy products and their isolated compounds such as lactoferrin and oligosaccharides have been employed as anti-infective agents against ETEC infections in piglets postweaning, and to improve intestinal health. The differences in amino acid composition in casein and whey have been thought to exert different immunomodulatory and metabolic effect, however, although differences in immunological responses between these dairy components were demonstrated (Sugiharto et al., 2014), no difference in plasma metabolic profile or performance or diarrhea response in piglets post weaning was observed. The dairy by-products (e.g., whey or whey permeate) may also be fermented to further improve the anti-infective potential of the products. Incorporation of whey permeate fermented with W. viridescens into liquid diets improved the performance of E. coli inoculated pigs post weaning (Sugiharto et al., 2015). Overall, the anti-infective activities of dairy-based products against ETEC could be attributed to the improvement of the intestinal barrier functions, microbial ecosystem and immunity of the piglets.

6.- CONCLUSION AND PERSPECTIVES

Prevention of colibacteriosis may not only influence performance of the piglet, but may also lead to improved welfare of the pig. A number of nutritional strategies have been suggested as alternative means of controlling post weaning diarrhea in piglets, and there are several possible modes of action by which nutrition or food components may influence the microbiota and/or the immunity of the pig. Currently it is however unlikely that there is any single substance that could replace the function of feed antibiotics.
7.- ABSTRACT

Postweaning diarrhea (PWD) is a significant enteric disease causing considerable economic losses for the pig industry. Among several etiological risk factors, enterotoxigenic Escherichia coli (ETEC) is considered to be a major cause, i.e. colibacillosis. After being routinely used for several decades to control bacterial disease outbreaks in piglets, the use of antibiotics at subtherapeutic concentrations has been banned in the European Union since 1st January 2006 due to the increasing prevalence of resistance to antibiotics in pigs. The removal of in-feed antibiotics from piglet diets has negative economic consequences as it dramatically increases the rate of morbidity and mortality due to ETEC as well as the use of antibiotics for therapeutic purposes. One of the promising substitutes for in-feed antibiotics is high pharmacological levels of dietary zinc, which is allowed with permission in Denmark and Belgium, but its excretion may have negative impacts on the environment. Thus, alternatives to antibiotics and high levels of heavy metal that can control ETEC infections in piglets postweaning will be of great advantage. A number of nutritional strategies have been proposed as alternative means of preventing ETEC infections, and the possible modes of actions by which the food or food components may prevent and/or reduce ETEC-diarrhea in pigs during the postweaning will be reviewed in the present paper.

8.- REFERENCES


