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BENEFICIAL ASPECTS OF INULIN SUPPLEMENTATION AS A FRUCTOOLIGOSACCHARIDE PREBIOTIC IN MONOGASTRIC ANIMAL NUTRITION – A REVIEW*

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Abstract

Inulin is widely used as a prebiotic additive in the nutrition of farm animals and pets. This fructooligosaccharide demonstrates a beneficial effect on host health by stimulating the growth and development of commensal bacterial species inhabiting the large intestine. Used for example in the feeding of piglets, inulin greatly enhances their daily body weight gains and also reduces the risk of anemia (Tako et al., 2008). In poultry, in the case of meat breeds, inulin provides better feed utilization, increases the daily gains and the final carcass weight (Ammerman et al., 1988). In laying hens, it positively stimulates the production of eggs (Chen et al., 2005). The addition of prebiotics in the diet of dogs has a positive effect on the concentration of the end products of sugar and protein fermentation in the colon, thus contributing to the health status and good condition of the animal (Flickinger et al., 2003 b; Middelbos et al., 2007). Moreover, inulin beneficially affects the efficiency of the immune system of the organism (including the anticarcinogenic properties) (Kelly-Quagliana et al., 1998), as well as lipids and the cholesterol metabolism by effectively reducing their concentrations in the blood serum (Grela et al., 2014 a). This paper characterizes inulin as a prebiotic additive in the diet of selected species of monogastric animals. In addition, data about the hypolipidemic and immunostimulatory properties of inulin are presented.

Key words: inulin, prebiotic, pigs, poultry, dogs

For proper and efficient animal nutrition, and in addition to the basic nutritional ingredients of feed, various types of substances, micro-organisms and/or their products, which are defined as feed additives, are also necessary. Until recently, antibiotic growth promoters (AGP), which beneficially affect animal growth and feed utilization rate, were commonly used in animal production. However, at present, the use

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of these types of additives is prohibited. The main reason for this ban was the abuse of AGP usage by livestock farmers and feed manufacturers, which in turn led to the acquisition of drug resistance by pathogenic microorganisms (Wegener, 2003). The withdrawal of AGP from animal production has led to the search for safe, alternative feed additives, which due to the unique properties of the active substances they contain, may effect more efficient production. It has been found that prebiotics, probiotics (Patterson and Burkholder, 2003), exogenous enzymes (Reilly et al., 2010), phytobiotics (Windisch et al., 2008) and organic acids (Lallès et al., 2009) can successfully replace antibiotics in stimulating growth and animal performance. Among the above-mentioned supplements, the most widely used additives are prebiotics, due to their ease of preparation, storage stability in feed and, above all, because of their strong stimulatory effect on the performance and health of animals. Among the whole range of prebiotic supplements, the most interesting seems to be inulin.

Inulin as a prebiotic

In nature, inulin serves as a reserve material for certain plants from the *Liliaceae* (garlic, onions, leeks) and *Compositae* (chicory, dahlia, Jerusalem artichokes) family. It can also be found in wheat, rye, oats, soybeans, barley, asparagus and bananas (Skowronek and Fiedurek, 2003; Kolida and Gibson, 2007). Most of the commonly available inulin in the food industry is synthesized from sucrose or extracted from chicory roots – *Cichorium intybus* (this may contain up to 15–20% inulin) (Niness, 1999). Purified inulin can also be produced from tubers of the Jerusalem artichoke or dahlias, also from kuth roots, burdock, goldenrod and dandelion.

The production process of extraction from chicory roots is similar to the extraction of sugar from sugar beets. First, the roots are harvested, then cleaned and after that sliced. Inulin is washed out from the roots with hot water, purified and dried. The final product also contains 6–10% sugars, such as glucose, fructose and sucrose, which are native to the chicory roots (Niness, 1999).

Inulin belongs to the fructan group. This consists of fructose subunits linked by β-2,1 bonds containing, at the reducing end, a single molecule of glucose. Glucose is linked by α-1,2 bonds to a fructose chain (Kolida and Gibson, 2007). β-2,1- linkages not only determine the specific properties of inulin, but also protect it from digestion in the upper part of GIT (gastrointestinal tract) and are responsible for its reduced caloric value and the effect of dietary fiber (Niness, 1999).

Inulin, with a degree of polymerization ranging from 3 to 60 (van de Wiele et al., 2007), when intact in the upper parts of the digestive tract, reaches the colon where it is degraded by enzymes (Niness, 1999; Hesta et al., 2006) produced by certain types of bacteria, such as *Arthrobacter*, *Bacillus*, *Clostridium*, *Flavobacterium*, *Pseudomonas*, *Staphylococcus* and *Lactobacillus.* These bacteria synthesize inulinases which can act both inside (endoinulinases) and outside (exoinulinases) of the chain on the β-2,1 bonds in inulin. As a result of the hydrolytic degradation of inulin (the performance of this process can be as high as 95%), free molecules of fructose and short chains of inulooligosaccharides are released (Skowronek and Fiedurek, 2003).

As a result of inulin fermentation carried out by colon microflora, formation occurs of short chain fatty acids (SCFA), lactic acid and gases: H_2, H_2S, CO_2 and CH_4

(Macfarlane and Gibson, 1997). It has been shown that among all SCFA, butyrate is the major product of inulin fermentation (Rossi et al., 2005). SCFA and lactate production contributes to the generation of useful energy equaling 1.5 kcal/ g of inulin; however, this represents only a small fraction in relation to the energy coming from the digestion of nutrients in the small intestine (Roberfroid et al., 1998). Other products of the hydrolytic degradation of inulin are excreted together with the bacterial biomass. All of these compounds may have varying effects on host health (Roberfroid et al., 1998; Niness, 1999; Hesta et al., 2006). Inulin is classified as a functional component, because in addition to its nutritional properties it positively affects more than one target function (associated with improved stage of health, well-being and/or reduction of risk of disease) such as increase Ca/Mg absorption, regularize bowel function, increase bone mineral content, reduce triglyceridemia, reduce cholesterolemia, improve resistance etc. (Roberfroid, 2007). It is used as an additive in feeds for many farm animals (pigs and poultry) and pets (dogs, cats, rabbits). It is expected that prebiotics such as inulin could be a part of the diets of livestock both to enable modulation of gut microflora and to stimulate animal productivity in natural ways (Samanta et al., 2013).

Immunomodulatory properties of inulin

There are several hypotheses about the effects of inulin on the immune system. It is believed that this effect may be either indirect or direct. An indirect impact refers to the stimulation of the development of beneficial gut microbiota strains, and the inhibi-tion of the proliferation of pathogenic bacteria causing infections and producing toxins harmful to the organism. However, the direct effect involves the stimulatory effect on phagocytosis carried out by the phagocytic cells in blood (Wójcik et al., 2007), as well as non-specific mechanisms of humoral immunity (Milewski et al., 2007).

Consumption of prebiotics, resulting in beneficial changes in the composition of the intestinal microfloral population, can mediate in immune stimulation through direct contact of health promoting bacteria or their products with cells of the immune system in the gut. By increasing the number of bifidobacteria, there will be increased competition with pathogenic bacteria for binding sites on the intestinal epithelium and for nutrients, thus inhibiting survival of the pathogenic strains. Beneficial members of the gut microbiota bacteria may also cross the intestinal barrier into the Peyer's patches, and activate immune cells there (Berg, 1985). Antibacterial substances produced by *Bifidobacterium* species and *Lactobacillius* also can inhibit the growth and survival of pathogens.

Also, production of SCFA derived from the fermentation of dietary fiber may have a significant impact on the immune system, such as acidification of the colonic environment, acidification of the colon favoring mucin production as well as binding to SCFA receptors on immune cells within the gut-associated lymphoid tissues (GALT) (Lomax and Calder, 2009).

The increased concentration of SCFA results in a higher number (Kelly-Quagliana et al., 1998) of natural killer (NK) cells and stimulates their activity. These substances also have anti-inflammatory effects, whereas mucus covering the digestive tract prevents adhesion and subsequent transfer of pathogenic bacteria through the walls of the epithelium. An increased production of mucin-rich mucus in animals receiving dietary fiber based feed contributes to reducing bacterial translocation through the intestinal barrier (Schley and Field, 2002). To colonize the GIT and to cause a disease, pathogenic microorganisms have to overcome a lot of physical barriers, such as the acidic pH of the gastric contents, the rapid passage through the small intestine, microflora living in the colon, the barrier constituted by the intestinal epithelium, and finally the host immune response. In addition, it has been shown that health promoting microorganisms are able to communicate in a specific way with the epithelium and the immune system, thereby controlling the physiology of the tissue and the ability to respond to infection (Patterson and Burkholder, 2003). Moreover, consumption of inulin-type fructans could be one way to modulate mucosa-associated biofilms so that members of the biofilm community, generally considered as health-promoting, are stimulated (Kleessen and Blaut, 2005).

It is believed that inulin enhanced with oligofructose (OF) causes beneficial changes in the immune function of GALT (Roller et al., 2004). The GALT is made up of the mucosa-associated lymphoid tissues of the gut, and is located underneath a columnar epithelial layer and mucus layer. Within the epithelial layer, M (microfold) cells, which are antigen-presenting cells and are capable of transporting antigen from the gut lumen into the Peyer's patches of the GALT, are distributed. In the Peyer's patches antigen-presenting cells process and present the antigen to lymphocytes become activated. These lymphocytes then travel through the thoracic duct and into the blood, where they become re-localized to the lamina propria of the intestine (Lomax and Calder, 2009).

It has been found in the earlier studies that inulin enriched with oligofructose enhances the cytotoxicity of NK cells produced in the spleen, intensifies cytokine production by spleen cells, and has stimulating properties on the immune response to carcinogenic agents (Watzl et al., 2005). However, not all research clearly confirms the positive effect of an inulin addition. Interesting results were obtained by Szymeczko et al. (2013) in studies on polar foxes. The addition of 0.5% inulin in the diet caused a decrease in the amount of hemoglobin and the average weight of hemoglobin in erythrocytes. The same authors report that increasing doses of inulin in the diet of polar foxes reduce the number of thrombocytes.

Indigestible carbohydrates may also exert some influence on the availability of some minerals. It has been noted that there is a significant stimulation of the absorption of magnesium, calcium (Scholz-Ahrens and Schrezenmeir, 2007), zinc, copper (Coudray et al., 2006) and iron (Tako et al., 2008), but this effect depends on the age of the animal subjected to the experiment, with better results in young animals.

Hypolipemic abilities of inulin

The effect of inulin and other prebiotics and probiotics has been well studied in terms of their hypolipidemic ability. The addition of inulin and oligofructose to animal diet has shown various effects: from a lack of noticeable changes induced by supplementation with the prebiotics to a significant reduction in the concentration of triglycerides in the blood plasma with moderate changes in the level of cholesterol (Gibson and Pereira, 2002). Trautwein et al. (1998) demonstrated that the addition of inulin in the diet of Syrian hamsters resulted in a reduced concentration of total cholesterol in the blood plasma, total cholesterol of liver, very-low-density lipoproteins (VLDL), triglycerides, taurochenodeoxycholic acid and a higher concentration of glycocholic and glycodeoxycholic acids. Moreover, it increased the secretion of acid bile in the feces of animals. The hypolipemic properties of inulin are caused by several mechanisms, of which the most important rely on indirect changes in the synthesis of hepatic triacylglycerols, VLDL secretion and the reverse absorption of bile acids.

Furthermore, the addition of inulin, resulting in a higher number of commensal bacteria in the large intestine, means that the fermentation of non-digestible carbohydrates in the small intestine leads to an increased concentration of SCFA in the colon, which in turn can cause a decrease in the concentration of blood lipids. This decrease occurs through the inhibition of cholesterol synthesis in the liver and its redistribution from plasma into this organ. In addition, there is the possibility to reduce the absorption of cholesterol by deconjugation of bile acids by certain bacteria. Deconjugation involves the disconnection of the taurine or glycine from a bile acid molecule, which impairs the absorption of cholesterol (Gibson and Pereira, 2002).

Inulin in the feeding of monogastric animals

A) Inulin in the feeding of poultry

During recent years, there has been an increase in the amount of research to assess the influence of inulin on the microflora of the alimentary tract, and the health and productivity of animals (digestibility, body weight gains, feed conversion). In most cases, the experiments have confirmed a beneficial influence on selected parameters. However, not all of the results are completely unambiguous. Detailed information on the influence of individual prebiotics in poultry is presented in Table 1.

Fructans contribute to changes in the intestinal bacterial microflora in chickens, which causes a growth of the *Lactobacillus* population in parallel to a decrease in bacteria colonies of the following species: *Escherichia coli*, *Campylobacter* and *Salmonella* (Xu et al., 2003; Yusrizal and Chen, 2003b). The last of the above bacteria are the main causes of infections in chickens just after hatch (Dankowiakowska et al., 2013). However, thanks to an innovative *in ovo* technology (Bednarczyk et al., 2011), these infections can be limited by injecting into the air cell of a developing embryo a prebiotic solution, which already at the embryonic stage starts to support the organism's immune system. At present, research is being conducted on the properties of inulin within this area.

The addition of inulin and oligofructose into poultry diet beneficially influences the morphology of intestines and cholesterol concentration levels in blood serum (Yusrizal and Chen, 2003 a). Beneficial changes have been noted within the small intestine, resulting in its better development and the thickening of the intestinal villus system. A 1% addition of inulin into compounded broiler chicken feed resulted in increased intestinal villus length and crypt depth in comparison with a control group (Rehman et al., 2007). Xu et al. (2003) demonstrated that prebiotic supplementation in the amount of 4 g/kg considerably increased intestinal morphology especially in terms of higher villus and more shallow crypts. Changes of this kind lead to enhanced absorption of nutrients (Rebolé et al., 2010).

Table 1. Effect of different prebiotic doses on animals (own study on the basis of the literature on the subject)

Author (year)	Prebiotic	Species	Dose in grams per kg of feed (% share in a dose)	Effect
1	2	3	4	5
Intestinal histomorphology				
Rehman et al. (2007)	inulin	broiler chicken	10 g/kg (1%)	The increase of intestinal villus height and crypt depth in comparison with a control group of broiler chickens; no changes in the ratio of villus height to crypt depth
Xu et al. (2003)	FOS	broiler chicken	4 g/kg (0.4%)	The increase of intestinal villus height in the ileum, microvillus height in the ileum and jejunum and shallower crypts of both ileum and jejunum
Xu et al. (2003)	FOS	broiler chicken	8 g/kg (0.8%)	No influence on intestine morphology
Yusrizal and Chen (2003 a)	inulin/OF	broiler chicken	10 g/kg (1%)	Higher density of jejunum villi distribution in the small intestines
Nabizadeh (2012)	inulin	broiler chicken	10 g/kg (1%)	No effect on villus height, crypt depth, or the villus height-to-crypt depth ratio of the duodenum and jejunum
Bacterial population				
Xu et al. (2003)	FOS	broiler chicken	4 g/kg (0.4%)	Increased amount of bacteria from species: *Bifidobacterium* and *Lactobacillus* and decrease in *Escherichia* coli in intestinal contents of the small intestine and cecum
Rebolé et al. (2010)	inulin	broiler chicken	10 g/kg (1%); 20 g/kg (2%)	Increased amount of bacteria from species: *Bifidobacterium* and *Lactobacillus* in intestinal contents of the small intestine and cecum; increased concentration of butyric acid and lactic acid
Kim et al. (2011)	inulin	broiler chicken	2.5 g/kg (0.25%); 5 g/kg (0.5%)	Decreased amount of *Escherichia coli* and *Clostridium perfringens*
Nabizadeh (2012)	inulin	broiler chicken	10 g/kg (1%)	No significant effect on the pH of digesta and microflora counts in the ileal contents but significantly increased *Bifidobacteria* counts and decreased *E. coli* counts in cecal contents

Yusrizal and Chen (2003 b)	OF	broiler chicken	10 g/kg (1%)	Reduced amount of total aerobe and *E. coli* in feces; increased *Lactobacilli* counts in gizzard and small intestine
Yusrizal and Chen (2003 b)	inulin/ OF	broiler chicken	10 g/kg (1%)	Reduced amount of *Campylobacter* in the large intestine and cecal content; reduced amount of *Salmonella* in cecal content; increased *Lactobacilli* counts
Bailey et al. (1991)	FOS	broiler chicken	3.75 g/kg (0.375%)	Decreased amount of *Salmonella typhimurium*
O'Shea et al. (2012)	inulin	fast growing pig	12.5 g/kg (1.25%)	Reduced population of *Enterobacteriaceae*
Estrada et al. (2001)	FOS	weaned piglet	5 g/kg (0.5%)	The beneficial influence on the growth of the *Bifidobacterium longum* population in the large intestine and the decrease in anaerobe and *Clostridium perfringens* populations in the feces
Tako et al. (2008)	inulin	piglet	10 g/kg (1%)	Health-promoting influence on the *Lactobacillus* and *Bifidobacterium* population in the large intestine
Russel (1998)	inulin	dog	10 g/kg (1%)	Higher Bifidobacteria concentration
Beloshapka et al. (2013)	inulin	dog	14 g/kg (1.4%)	Reduced abundance of fecal *Enterobacteriaceae*, *Escherichia*, *Bacteroides* and *Fusobacterium* as well as higher number of *Lactobacillus*
Flickinger et al. (2003 b)	FOS	dog	3 g/kg (0.3%)	Increase in the total amount of aerobes, decrease in *Clostridium perfringens*
			Performance results	
Yusrizal and Chen (2003 a)	inulin/ OF	broiler chicken	10 g/kg (1%)	Improved weight of carcass, body weight gain, feed conversion, carcass percentage and increased gut length
Yusrizal and Chen (2003 a)	inulin	broiler chicken	10 g/kg (1%)	Reduced serum cholesterol and abdominal fat
Yusrizal and Chen (2003 b)	inulin/ OF	broiler chicken	10 g/kg (1%)	Reduced volatile ammonia and fecal pH in fresh feces during the first 4 weeks of production
Rebolé et al. (2010)	inulin	broiler chicken	10 g/kg (1%)	Better weight gains in male broiler chickens

Table 1 – contd.

1	2	3	4	5
Ammerman et al. (1988)	FOS	broiler chicken	2.5 g/kg (0.25%); 5 g/kg (0.5%)	Increase in feeding efficiency, decrease in mortality of young broiler chickens
Ammerman et al. (1988)	FOS	broiler chicken	7.5 g/kg (0.75%)	Body weight gains in broilers and improvement of carcass characteristics (increase in weight of warm carcass) in comparison with a control group
Chen et al. (2005)	inulin	laying hen	10 g/kg (1%)	Increase in reproductive efficiency of laying hens by 13.3% in comparison with laying hens from a control group; increased total weight of eggs; better feed consumption
Nabizadeh (2012)	inulin	broiler chicken	10 g/kg (1%)	Higher body weight gains
Grela et al. (2013)	inulin	fattening pig	30 g/kg (3%)	Increase in daily body weight gains
Sobolewska and Grela (2013)	inulin	fattening pig	20 g and 30 g/kg (2% and 3%)	A positive effect on the feed conversion ratio, daily weight gain
Kjos et al. (2010)	inulin	fattening pig	42–63 g/kg (4.2–6.3%)	A positive impact on production results: the bigger the share of inulin in the feed, the more evident are the increases in body weight gains during the first and second periods of fattening
Estrada et al. (2001)	FOS	weaned piglet	5 g/kg (0.5%)	Higher daily gains and better feed efficiency relative to the control group

FOS – fructooligosaccharides; OF – oligofructose.

Moreover, it has been shown that an inulin addition to compound feeds for chickens has a positive influence on the production results achieved by birds. Yusrizal and Chen (2003 a) observed that a 1% addition of inulin increased the weight of the carcass, but only in females, whereas Rebolé et al. (2010) noted better weight gains in male broiler chickens at the same dose of inulin. Similarly, Ammerman et al. (1988) demonstrated an increase in feeding efficiency, a decrease in mortality and an improvement of post-slaughter parameters in slaughter chickens. Beneficial changes have also been observed in the case of inulin and oligofructose supplementation to laying hens. This supplementation resulted in increased egg production and increases in total egg weight per week (Chen et al., 2005).

Microarray based gene expression study on the effect of inulin supplementation in broilers has been reported for the first time by Sevane et al. (2014). They showed that functional annotation analyses revealed a number of genes, processes and pathways that are associated with chicken growth and performance, by strenghtening the immune status of animals, and fostering the production of long chain fatty acids in broiler chickens.

B) Inulin in the feeding of pigs

The influence of inulin, as well as other prebiotics, on selected production and health parameters has also been examined in pigs. It has been proved that in pigs inulin is mainly digested in the cecum (Yasuda et al., 2007). Inulin used in fattening pig diet considerably increases their daily body weight gains (Grela et al., 2013). When served in large amounts (20 and 30 g per kg of feed mixture) to growing pigs, inulin has a positive effect on the feed conversion ratio, daily weight gain and crude fiber digestibility (Sobolewska and Grela, 2013) (Figure 1). The results of research conducted by Kjos et al. (2010) suggest a positive impact on production results can be achieved with an inulin supplemented diet (4.2–6.3% of pure inulin in kg of diet) administered to fattening pigs; i.e. the bigger the share of inulin in the feed, the more evident are the increases in body weight gains during the first and second periods of fattening. Moreover, inulin supplemented to a finisher diet for porkers in amounts over 4% contributes to the reduction of skatole levels in intestinal contents and adipose tissue (Kjos et al., 2010). High skatole levels in pig tissues lead to ‘boar taint’, a sex-specific odor from pork, so reduction of skatole amount is important from consumer point of view (Wesoły and Weiler, 2012). It has been shown that fructooligosaccharides (FOS) used in the diet of weaned piglets have a favorable impact on the increase in size of beneficial micro-organism populations, which in turn protect piglets against the multiplying of pathogenic strains. This kind of help ensures healthier intestines, which leads to better gains and a better use of feed (Shim et al., 2004). Another interesting study on post-weaned piglets has been performed by Awad et al. (2013). They showed that diet with 3% inulin increased the glucose transport and improved intestinal permeability in the jejunal mucosa of piglets after weaning. Moreover, inulin additive offers a promising approach to avoid post-weaning gastrointestinal tract disorders in piglets, because it enhances absorption of glucose in small intestine.

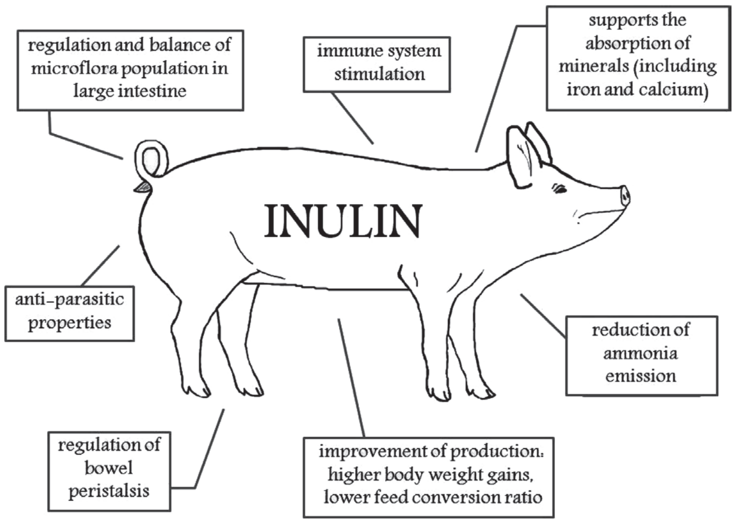

Figure 1. Inulin effects in porcine organism (own study on the basis of the literature on the subject)

Large doses of inulin (12.5 g per kg) in the diet of fast-growing pigs reduce the population of *Enterobacteriaceae* (O'Shea et al., 2012) (Figure 1). It has been also shown that inulin addition stimulates the proliferation of beneficial intestinal bacteria strains (Metzler-Zebeli et al., 2009; Janczyk et al., 2010), thus reducing the risk of dysentery occurring in pigs (Hansen et al., 2010; Hansen et al., 2012). Additionally, Estrada et al. (2001) observed the beneficial influence of fructooligosaccharides on the growth of the *Bifidobacterium longum* population in the large intestine and the decrease in anaerobe and *Clostridium perfringens* populations in the feces of weaned piglets. An experiment conducted by Tako et al. (2008) confirmed the health-promoting influence of inulin usage on the *Lactobacillus* and *Bifidobacterium* population in the large intestine in piglets. Furthermore, the team proved the beneficial effect of this prebiotic on the expression of proteins that participate in binding and transporting iron ions in the intestines of 5-week-old piglets with anemia through increasing levels of DMT1 (the divalent metal transporter 1), Dcytb (duodenal cytochrome B), ferroportin, ferritin and TFR in the duodenum, and DMT1, TFR and ferritin in the colon. The authors claim that there are two pathways by which inulin might affect intestinal gene expression. One is increased soluble Fe in the intestinal lumen and the second is increased production of SCFA in the colon lumen leading to a possible systemic effect of butyrate on Fe metabolism. A 4% addition of inulin into piglet diet caused a 28% improvement in hemoglobin saturation, 15% increase in hemoglobin concentration in the blood and a higher concentration of iron dissolved in the proximal, middle, and distal parts of the large intestine, as well as a lower concentration of hydrogen sulfide in the final part of the large intestine (Yasuda et al., 2006). Grela et al. (2014 b) examined the effect of inulin extracts or inulin-containing plant (dandelion, chicory and Jerusalem artichoke powder) on lipid indices and fatty acid profile in fattener tissues. The results have shown that dietary supplement of 40 g dandelion powder may cause significant and beneficial changes in the blood lipid indices and fatty acids composition (increased polyunsaturated fatty acids share and decreased *n-6*/*n-3* ratio). The assessment of the effect of different inulin source on piglet performance, plasma lipid profile, and immunoglobulin concentration has shown that both extracts or dried plants may significantly improve the rearing indices (Grela et al., 2014 a). Furthermore, inulin showed hypolipidemic activity manifested by lowered total cholesterol level and stimulated piglet immune system (elevated IgA and IgG concentrations) (Grela et al., 2014 a). Another study indicates that an increased inulin level (3%) positively affected the lipid parameters, such as the content of triacylglycerols, total cholesterol and high density lipoprotein fraction (HDL) in fattener blood plasma as well as the production of short-chain fatty acids in the large intestine (increased concentration of acetic, isobutyric and butyric acids (cecum) as well as acetic and butyric acids (colon)) (Sobolewska et al., 2014). Moreover, it has been proved that inulin reduces the amount of nitrogen emitted into the atmosphere, possibly by reducing excreta pH and populations of bacteria, as well as changing bacterial metabolic activities (Halas et al. 2010). Furthermore, 0.3% inulin addition to diet of growing pigs tends to shift nitrogen excretion from urine to feces (Loh et al., 2010). This has a positive impact on the environment.

Worth mentioning are the anti-parasitic properties of inulin (Figure 1). It has been proved that inulin can successfully inhibit the development of some parasites existing in the large intestine, for instance *Oesophagostomumdentatum* and *Trichurissuis* (Petkevičius et al., 2003; Petkevičius et al., 2007; Kjos et al., 2010).

C) Inulin in the feeding of dogs

Studies on the effectiveness of selected prebiotics in foods for small animals have also been performed (Swanson et al., 2002; Flickinger et al., 2003 a, b; Propst et al., 2003; Verdonk et al., 2005; Beloshapka et al., 2012, 2013; Strompfová et al., 2013; Pinna and Biagi, 2014). It has been shown that the values of selected parameters are influenced not only by the type of the fructan used, but also its concentration in a diet, the type of diet (animal- or plant-based), into which they were included (Propst et al., 2003), individual features of animals and the sanitation of buildings, in which animals are kept (Verdonk et al., 2005).

In research conducted by Propst et al. (2003), it was shown that the total phenol production in feces considerably decreased due to inulin supplementation and branched-chain fatty acids (BCFA) concentration decreased due to oligofructose supplementation. Both fructans contributed to the increase of SCFA concentration levels in the large intestine. In turn, raw meat-based diet with 1.4% of inulin resulted in increased fecal SCFA and spermine concentrations (Beloshapka et al., 2012). Among the benefits of higher concentrations of propanoic, butyric and acetic acids are the regulation of calcium and magnesium cation absorption, control of lipid and cholesterol changes, as well as the increase in the intestine's ability to absorb through stimulation of epithelium cell proliferation. Moreover, butyric acid is a source of energy for colonocytes, contributes to an increase in intestine crypt depth and its high concentration indirectly prevents neoplasm (Topping, 1996).

Similarly, it has been proved that there is a favorable relationship between inulin supplementation in a dog's diet and intestinal microflora. In dogs fed a diet with a 1% inulin addition a higher Bifidobacteria concentration was noted than was the case in dogs from a control group (Russel, 1998). Other observed changes of bacterial populations in dogs supplemented with inulin (14 g/kg of diet) were reduced abundance of fecal *Enterobacteriaceae*, *Escherichia*, *Bacteroides* and *Fusobacterium* as well as higher number of *Lactobacillus* (Beloshapka et al., 2013). Hussein et al. (1999), Loo (2007) and Kelly (2008) simultaneously observed fewer pathogen micro-organisms.

High concentrations of prebiotics in diets may have effect on fecal consistency. Thus, prebiotics should be administered to dogs at relatively low level – less than 20 g/kg of dietary dry matter to maintain feces more firm (Pinna and Biagi, 2014). Strompfová et al. (2013) highlighted the positive role played by a combination of *Lactobacillus fermentum* (1% of diet) and inulin on stool consistency. Slight laxative effect of them can be useful in senior dogs to prevent constipation.

Among other prebiotics the implementation of a diet enriched with short-chain fructooligosaccharides (2–3 g per day) resulted in higher nutrient digestibility and lower amount of excreted feces, whereas no considerable changes were noted in the concentrations of SCFA (in contrast to previously mentioned studies with inulin), BCFA, ammonia, phenols or indoles. The total amount of aerobes increased with a simultaneous decrease in *Clostridium perfringens* (Flickinger et al., 2003 b). The health-promoting effect of FOS with cellulose and beet pulp on butyrate production, SCFA concentration and populations of *Lactobacillus* and *Bifidobacterium* was confirmed by Middelbos et al. (2007). Swanson et al. (2002) summed up the favorable effect of mannooligosaccarides (MOS) supplementation, as it is a nutrient beneficially changing the microbiological population in the large intestine and affecting in a desirable way the functions of the immune system in dogs, while FOS supplementation was assessed as beneficial for its inhibiting effects on the concentration of decomposition substances in feces. Thus, implementation of these prebiotics may show the strongest effects in feeding dogs with a disordered balance of microorganisms in the intestines and a weakened immune system, namely in weaned dog pups, older dogs and stressed animals (Swanson et al., 2002). The future research on prebiotics as functional food ingredients in monogastric animal nutrition should focus on the following: (i) the development of a method for the cost effective production of prebiotics, (ii) an investigation into their mechanism of action and (iii) an examination of prebiotic potentiality on animal systems in terms of production quality and quantity (Samanta et al., 2013).

Summary

The withdrawal of antibiotic growth promoters in animal feed has necessitated the search for alternative supplements, which could improve the intestinal microflora composition and thus enhance animal health conditions. A lot of research indicates that inulin added into compound feed and foods favorably changes the bacterial population profiles (Hussein et al., 1999; Estrada et al., 2001; Tako et al., 2001; Xu et al., 2003; Wang, 2005; Loo, 2007; Rebolé et al., 2010) and production results achieved by farm animals (Ammerman et al., 1988; Yusrizal and Chen, 2003 a; Kjos et al., 2010; Grela et al., 2013). It has been confirmed that an inulin addition in a diet also shows an immunostimulating effect (Roller et al., 2004; Watzl et al., 2005). However, according to research results, the effectiveness of the prebiotic features of fructans depends on numerous factors, among others it depends on their dose in animal diet – generally, higher doses give more noticeable and beneficial effects. It is worth remembering that the growing of plants from which inulin can be acquired is relatively simple and the process of polysaccharide acquisition is uncomplicated. These merits without any doubt may contribute to the increase in the usage of inulin in the feeding of monogastric animals.

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