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DIETARY FRUCTANS AND THEIR POTENTIAL BENEFICIAL INFLUENCE ON HEALTH AND PERFORMANCE PARAMETRS IN BROILER CHICKENS

POKARMOWE FRUKTANY I ICH POTENCJALNY KORZYSTNY WPŁYW NA ZDROWIE I WYNIKI PRODUKCYJNE U KURCZĄT BROJLERÓW

Monika BOGUSŁAWSKA-TRYK*, Anna PIOTROWSKA and Katarzyna BURLIKOWSKA

Department of Animal Physiology, Faculty of Animal Breeding and Biology, University of Technology and Life Sciences, Mazowiecka 28, 85-084 Bydgoszcz, Poland
*Corresponding author: dr Monika Bogusławska-Tryk, Department of Animal Physiology, Faculty of Animal Breeding and Biology, University of Technology and Life Sciences, Mazowiecka 28, 85-084 Bydgoszcz, Poland.
Tel. +48 52 3749754, fax +48 52 322 8158, e-mail: monikab@utp.edu.pl

ABSTRACT

Fructans, which include inulin and fructooligosaccharides, are non-digestible carbohydrates that are fermented in the large intestine. This review focuses on the effect of these prebiotics on gut microflora, fermentation characteristics, gut morphology, enzymes activity, nutrients digestibility and absorption, lipids metabolism and performance parameters in broiler chickens. Inulin-type fructans can improve performance of birds and health by affecting microbial community in the gastrointestinal tract, gut morphology and nutrient digestion. It is documented that dietary fructans influence the intestinal gut microflora of broiler chickens by increasing the population of *Bifidobacterium spp*., *Lactobacillus spp.* and *Eubacterium spp*. while decreasing the concentration of *Clostridium spp.* and *Escherichia coli* in the large intestine and caeca. The supplementation of poultry diets with inulin or oligofructose can lead to an increase of the length of small and large intestines in broilers, elongation of the villus in the chickens jejunal mucosa and increase in the ratio of villus height to crypt depth. The beneficial effect of inulin-type fructans on performance parameters in broilers may be partially explained by the elevated intestinal enzymatic activity under the influence of the fructooligosaccharides and increase of digestibility and absorption of nutrients, mainly protein and fat. The prebiotic effectiveness of inulin-type fructans in broilers depends on a number of factors, like the type of supplement (inulin vs. oligofructose), inclusion level, composition of the basal diet, animal characteristics (age, sex, stage of production) and hygienic conditions (i.e. stress factors).

KEYWORDS: inulin, fructooligosaccharides, broiler, gut microflora, gut morphology, performance

ABSTRAKT

Fruktany, do których zaliczane są inulina i fruktooligosacharydy, należą do niestrawnych węglowodanów, podlegających bakteryjnej fermentacji w jelicie

grubym. Niniejszy artykuł dotyczy wpływu tych prebiotyków na mikroflorę jelit, procesy fermentacji bakteryjnej, morfologię jelita, aktywność enzymów, strawność i absorpcję składników pokarmowych, metabolizm tłuszczów i wskaźniki produkcyjne u kurcząt brojlerów. Inulina i FOS mogą wpływać korzystnie na efekty produkcyjne i zdrowie ptaków poprzez oddziaływanie na populację bakteryjną w przewodzie pokarmowym, strukturę jelita i strawność składników diety. Wykazano, że pokarmowe fruktany wpływają korzystnie na mikroflorę jelitową kurcząt brojlerów poprzez wzrost liczby bakterii z rodzaju *Bifidobacterium, Lactobacillus* i *Eubacterium* oraz obniżenie ilości *Clostridium spp* i *Escherichia coli* w jelicie grubym i jelitach ślepych. Suplementacja diet dla drobiu inuliną lub oligofruktozą prowadzi do zwiększenia długości jelita cienkiego i grubego, wydłużenia kosmków w śluzówce jelita czczego u kurcząt oraz wzrostu stosunku wysokości kosmków do głębokości krypt jelitowych. Korzystny wpływ fruktanów na wskaźniki produkcyjne u kurcząt brojlerów może być częściowo efektem wzrostu aktywności enzymów śluzówki jelita cienkiego pod wpływem stymulującego działania tych prebiotyków oraz wzrostu strawności i absorpcji składników diety, głównie białka i tłuszczu. Efektywność prebiotycznego działania fruktanów zależy od szeregu czynników, takich jak: rodzaj stosowanego prebiotyku (inulina lub FOS), poziom suplementacji, skład diety bazowej, charakterystyka zwierząt (płeć, wiek) oraz warunki środowiskowe odchowu ptaków.
SŁOWA KLUCZOWE: inulina, fruktooligosacharydy, brojler, mikroflora jelitowa, morfologia jelita, wskaźniki produkcyjne

DETAILED ABSTRACT

W trosce o zdrowie zwierząt i zwiększenie efektywności produkcji, a także zaspokojenie oczekiwań konsumentów na bezpieczną żywność, poszukuje się alternatywy dla antybiotykowych promotorów wzrostu. Naturalnymi składnikami pasz, wykazującymi prebiotyczny wpływ na ustrój zwierzęcia, są polifruktany (inulina) i fruktooligosacharydy (FOS), które są przedmiotem intensywnych badań prowadzonych na różnych gatunkach zwierząt, również na drobiu. Do roślin uprawnych gromadzących duże ilości fruktanów należy m.in. cykoria, a znaczące ilości tych węglowodanów występują również w produktach zbożowych, głównie pszenicy i jęczmienia, które stosowane są jako komponenty pasz dla drobiu (Hussein i wsp., 1998; Kubik i wsp., 2006). Inulina i FOS stosowane w żywieniu zwierząt pozyskiwane są głównie z korzeni cykorii (*Cichorium intybus*) (Kubik i wsp., 2006; Rehman i wsp., 2009). Ze względu na strukturę chemiczną (wiązania β-(2-1) glikozydowe) są oporne na działanie endogennych enzymów glikolitycznych jelita cienkiego i w niezmienionej postaci docierają do jelita grubego, gdzie są metabolizowane przez mikroflorę jelitową do krótkołańcuchowych kwasów tłuszczowych (SCFA), mleczanów i innych metabolitów (Sabater-Molina i wsp., 2009), a tempo ich rozkładu zależy od stopnia polimeryzacji łańcucha (Roberfroid i Delzenne, 1998). Zakwaszenie środowiska i obniżenie pH treści jelita sprzyja namnażaniu się korzystnej mikroflory jelitowej, co hamuje wzrost i aktywność potencjalnych bakterii patogennych w przewodzie pokarmowym (Ferket, 2003; Flickinger i wsp., 2003; Sabater-Molina i wsp., 2009). Zmiany w populacji bakteryjnej mogą wpływać korzystnie na histomorfologię jelita, aktywność enzymów jelitowych, procesy trawienia i wchłaniania, metabolizm składników, a w efekcie na wyniki produkcyjne.

Jak wykazano w badaniach *in vivo* wprowadzenie inuliny lub FOS do mieszanek dla kurcząt brojlerów korzystnie zmienia populację bakteryjną nie tylko jelita grubego i jelit ślepych, ale również jelita cienkiego ptaków, poprzez wzrost liczby bakterii z rodzaju *Bifidobacterium, Lactobacillus* i *Eubacterium* oraz obniżenie ilości *Clostridium spp* i *Escherichia coli* (Bailey i wsp., 1991; Biggs i wsp., 2007; Kim i wsp., 2011; Patterson i wsp., 1997; Rebolé i wsp., 2010; Xu i wsp., 2003; Yusrizal i Chen, 2003a). Wykazano również, że fruktooligosacharydy mogą być czynnikiem ograniczającym kolonizację jelit ślepych oraz zanieczyszenie tuszek brojlerów przez bakterie z rodzaju *Salmonella typhimurium,* jednak skuteczność działania FOS w tym zakresie nie jest jednoznaczna i zależy m.in. od formy dodatku i jego ilości wprowadzonej do diety (Bailey i wsp., 1991; Chambers i wsp., 1997; Waldroup i wsp., 1993). Efektem działania SCFA powstających w procesach fermentacji bakteryjnej inuliny i FOS są korzystne zmiany w strukturze śluzówki jelita kurcząt. Obserwuje się wydłużenie i zagęszczenie kosmków i mikrokosmków oraz spłycenie krypt jelitowych w błonie śluzowej jelita czczego i biodrowego ptaków, co sprzyja absorpcji składników pokarmowych (Chen i wsp., 2005; Rebolé i wsp., 2010; Rehman i wsp., 2007; Xu i wsp., 2003; Yusrizal i Chen, 2003b). Wielu autorów potwierdza korzystny wpływ dodatku inuliny i FOS do diet dla brojlerów kurzych na wskaźniki produkcyjne (Ammerman i wsp., 1988, 1989; Kim i wsp., 2011; Li i wsp., 2008; Rebolé i wsp., 2010; Velasco i wsp., 2010; Xu i wsp., 2003; Yusrizal i Chen, 2003b). Poprawa parametrów produkcyjnych może być częściowo efektem wzrostu aktywności enzymów śluzówki jelita cienkiego pod wpływem stymulującego działania fruktanów oraz wzrostu strawności i absorpcji składników diety, głównie białka i tłuszczu (Alzueta i wsp., 2010; Williams i wsp., 2008; Xu i wsp., 2003). Nieliczne badania na kurczętach brojlerach wykazały, iż fruktany mogą wpływać na ogólnoustrojowy metabolizm lipidów, obniżając koncentrację tłuszczów i cholesterolu w wątrobie, redukując zawartość cholesterolu i triacylogliceroli w surowicy krwi ptaków oraz zmieniając korzystnie profil kwasów tłuszczowych w tkankach brojlerów (Velasco i wsp., 2010; Yusrizal i Chen, 2003b).

Z przeprowadzonych dotychczas na brojlerach kurzych badań wynika, że efektywność prebiotycznego działania fruktanów zależy od szeregu czynników, takich jak: rodzaj stosowanego prebiotyku (inulina lub FOS), poziom suplementacji, skład diety bazowej, charakterystyka zwierząt (płeć, wiek) oraz warunki środowiskowe odchowu ptaków. W zakresie zdrowia ptaków i poprawy parametrów produkcyjnych skuteczność działania inuliny i FOS może być porównywana z działaniem antybiotykowych promotorów wzrostu.

INTRODUCTION

Many feed additives are recommended to improve animal health, performance, immunity and growth. Among others, antibiotics have commonly been used as growth promoters (AGP) in the intensive animal production for many years. However, the implement the diets with antibiotics resulted in occurrence of antibiotic-resistant microorganisms (Sørum and Sunde, 2001), also potential pathogens of the genus *Streptococcus, Escherichia, Salmonella* (Aarestrup et al., 2001; Butaye et al., 2001). Moreover, it can disturb the bacterial ecosystem of the host organism (Andremont, 2000) and may lead to drug residues in products of animal origin (Różańska, 1999). The growing concern of health specialists, consumer groups and animal producers led to a ban of AGP usage in 2006 in the European Union

countries. It has resulted in search of effective alternatives, such as herbs, probiotics and prebiotics, which can enhance the immunity of the host organism against pathogenic infections. According to Gibson and Roberfroid (1995), prebiotics are "nondigestible food that beneficially affect the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon". Functional feed ingredients that exhibit the prebiotic effect on an animal organism are inulin-type fructans, such as inulin and oligofructose, which are the object of intensive scientific studies performed on different animal species, including poultry. This review describes the potential impact of inulin and oligofructose on the intestinal bacteria (Table 1), intestinal morphology parameters (Table 2) and growth parameters (Table 3) in broiler chickens.

INULIN AND OLIGOFRUCTANS - DEFINITION AND PREBIOTIC PROPERTIES

In plants, fructans occur mainly in the form of long-chain inulin and short-chain fructooligosaccharides (FOS). The most common sources of fructans are crops like chicory, topinambour, artichoke, asparagus, bananas, garlic, onion and leek (Kubik et al., 2006). A substantial content of these carbohydrates also occurs in cereals, like barley, wheat and their coproducts (Hussein et al., 1998), which are ingredients for poultry diets. Inulin and oligofructose used in animal nutrition originate mainly from chicory roots (*Cichorium intybus*) (Kubik et al., 2006; Rehman et al., 2009). Chemically, inulin extracted from chicory is a heterogeneous material with varying degrees of polymerization (DP). It is composed of a set of molecules of sucrose of which the fructose moiety is substituted with a linear chain of β-(2-1) fructans (Van Loo, 2007). A glucose molecule typically resides at the end of each fructose chain and is linked by an α-(1-2) bond, as in sucrose (Flickinger et al., 2003). The chain length of chicory inulin ranges from 2 to 70 (average, 10-20). The number of fructose units in oligofructose obtained by partial enzymatic hydrolysis of chicory inulin varies from 2 to 10 (average, 5) (Roberfroid and Delzenne, 1998). Lewis (1993) defined FOS as a mixture of 1-kestose (1-kestotriose; GF_2), nystose (1,1-kestotetraose; GF_3), and 1^F-fructofuranosyl-nystose (1,1,1-kestopentaose; GF_4). Because of their chemical structure (β-(2-1) glycosidic bond) inulin and oligofructose are resistant to hydrolysis by animal endogenous digestive enzymes in the upper gastrointestinal (GI) tract. With unchanged structure they enter the large intestine where are fermented by colonic microbiota. The bacterial degradation of fructans occurs in two phases. Initially, they are hydrolyzed by bacterial beta-oxidases to monomers, and than monomers are fermented to short chain fatty acids (SCFA) such as acetate, propionate and butyrate (Sabater-Molina et al., 2009). Main benefits which SCFA can provide to the host organism include: the use of acetic acid as an energy source for the peripheral tissues, utilization of propionic acid by the liver for gluconeogenesis and utilization of butyric acid by colonocytes as a primary energy fuel (Choct and Kocher, 2000; Montagne et al., 2003). The process of volatile fatty acids formation leads to acidification and lowering pH of the ileal environment and promotes the growth of beneficial types of bacteria, including Bifidobacteria, Lactobacilli and Eubacteria in the large bowel. The intensive growth of beneficial microbiota suppress the growth/activity of putrefactive and potentially pathogenic bacterial species which are responsible for production of toxic substances like ammonia, amines, nitrosoamines, phenols, indole or secondary bile acids. Moreover, Bifidobacteria have the ability to produce antibacterial substances, like bacteriocine,

that inhibit the growth of enteropathogens (Ferket, 2003). It is known, that *Salmonella spp.*, *Campylobacter spp., Clostridium perfringens* and *Eschericha coli* are the main enteropathogenic bacteria in poultry (Flickinger et al., 2003; Sabater-Molina et al., 2009).

As mentioned earlier, inulin-type fructans extracted from chicory roots are heterogeneous material consisting of sugars with varying degrees of polymerization (DP). This property is important in animal nutrition. According to Roberfroid et al. (1998), the fermentation rate decreases with increasing polymerization degree (DP) and chain elongation, however it generally has no effect on qualitative composition of the intestinal flora which remains bifidogenic. *In vitro* fermentation of inulin-type, fructans performed using human fecal flora as an inoculum, showed that the rate of inulin fermentation might be lower than that of oligofructose. It has been demonstrated that oligosaccharides are rapidly and completely metabolized by human fecal microflora and the rate of degradation of the oligomers with a DP lower than 10 is approximately twice than that of the molecules with the higher DP (Roberfroid and Delzenne, 1998).

EFFECT OF DIETARY FRUCTANS ON MICROBIAL POPULATION IN CHICKEN GASTROINTESTINAL TRACT

Due to differences in diets composition, intestinal morphology and its function, there is a great variation in the intestinal microflora of domestic animals. Generally, chickens have a very rapid intestinal digesta transit. The mean retention ororectum time does not exceed 6.5 hours (Van der Klis et al., 1990). Relatively large caeca are perpendicular to the GI tract and solid particles of digesta, also nondigestible fructans, are evacuated by ileocaecal valve into caeca. In chickens, this segment of GI tract is the primary site of bacterial fermentation. The bacterial cell content in chicken's caeca is approximately 10^{11} CFU/g digesta and 200 or more strains of bacteria represent this microflora (Flickinger et al., 2003). The most common bacterial species present in caeca are Bacteroides, Lactobacilli, Peptococci, Streptococci, Bifidobacteria, *Eschericha coli* and *Clostridium welchii* (Flickinger et al., 2003; Timms, 1968). Normal intestinal microflora such as *Bifidobacterium spp.* and *Lactobacillus spp.* use inulin or oligofructose for fermentation more efficiently than other groups of bacteria (Ferket, 2003; Yusrizal and Chen, 2003a). In pure cultures, all strains of bifidobacteria producing beta-glucosidase enzyme, except from *Bifidobacterium bifidum,* can carry out the rapid fermentation of inulin-type fructans, which are as good fermentation substrate as glucose (Roberfroid and Delzenne, 1998). However, not all colon bacteria can utilize fructans as a carbon source in the fermentation process. These include pathogens like *Eschericha coli* and *Clostridium perfringens* (Ferket, 2003). Patterson et al. (1997) in *in vitro* studies demonstrated that a number of bacterial species, including *Eschericha coli, Clostridium perfringens*, *Bacteroides thetaiotaomicron*, *Bifidobacterium bifidum*, did not grow on kestose oligosaccharides produced from pyrolysis of sucrose (i.e. thermal kestoses). On the other hand, thermal kestoses stimulated the growth of specific bacteria strains, both nonpathogenic and pathogenic, in pure culture. Patterson et al. (1997) observed the extensive growth of *Bacteroides fragilis*, *Bifidobacterium breve*, *Clostridium butyricum*, *Klebsiella pneumoniae*, and a slight growth of a number of species, including *Lactobacillus acidophilus* and *Lactobacillus salivarius*. However, these results do not indicate which species would predominate in the competitive

environment of the intestinal tract of broilers fed a diet supplemented with oligosaccharides.

A number of *in vivo* studies showed that dietary fructans influenced the intestinal bacterial community of broiler chickens by increasing the population of *Bifidobacterium spp*., *Lactobacillus spp.* and *Eubacterium spp*. while decreasing the concentration of *Clostridium spp.* and *Escherichia coli* in the large intestine and caeca (Bailey et al., 1991; Biggs et al., 2007; Kim et al., 2011; Patterson et al., 1997; Rebolé et al., 2010; Xu et al., 2003; Yusrizal and Chen, 2003a) (Table 1). It is demonstrated that in chicks dietary inulin and fructooligosaccharides may be fermented, to some extent, in the small intestine. According to Xu et al. (2003), the addition of 4.0 g/kg FOS to the basal diet significantly increased the viable count of *Bifidobacterium* and *Lactobacillus* in the small intestinal digesta, whereas the number of *Eschericha coli* was significantly reduced compared to the control group. Yusrizal and Chen (2003a) studied the effect of adding chicory fructans to feed on microflora in different intestinal segments in broiler chickens. It was demonstrated that feeding broilers with diets supplemented with 1% of oligofructose, but not with 1% of inulin, increased the *Lactobacilli* count in the gizzard and small intestine digesta. Recent studies performed on broilers also proved that supplementation of the diet with 0.25% FOS resulted in a significant decrease of *Clostridium perfringens* and *Escherichia coli* population and an increase in the diversity of Lactobacillus community in the ileum (Kim et al., 2011). Salmonella contamination of chickens carcasses is very important from the health specialists' and consumers' perspective. It is demonstrated that the control of *Salmonella* is achieved by low pH and high level of volatile fatty acids in broiler caeca content (Corrier et al., 1990a, 1990b). *In vitro* studies showed that *Salmonella typhimurium* did not grow when FOS was the sole carbon source (Bailey et al., 1991), therefore feeding oligofructose may be a practical strategy for controlling *Salmonella* in chicks. However, studies conducted on broilers to examine the potential effect of dietary fructans on Salmonella colonization of the chicken intestine and contamination of processed broiler carcasses are not unambiguous. It has been shown that chicory fructans did not clearly affect the colonization of *Salmonella spp.* in the digesta of the small intestine and caeca, except for lower caecal Salmonella count in 42-day-old female broilers (Yusrizal and Chen, 2003a). Chambers et al. (1997) found that at 6-week of age, broilers fed crude FOS from Jerusalem artichokes (5% of a diet) had higher *Salmonella typhimurium* count in caeca, whereas broilers fed diets containing 5% of refined FOS had lower infections than control chickens. Moreover, there was no consistent effect of caecal pH observed in chicks fed diets with crude and refined FOS on *Salmonella* infection. Bailey et al. (1991) reported that 0.375% FOS in the diet was insufficient to affect caeca colonization of *Salmonella typhimurium*, whereas 0.75% level decreased by 12% the number of birds that were colonized with *Salmonella* compared with control broilers. This effect was much more pronounced when chickens were stressed by feed and water deprivation. Broilers treated with 0.75% FOS had a four-fold reduction in the level *of Salmonella typhimurium* in the caeca (Bailey et al., 1991). Waldroup et al. (1993) conducted two similar trials to evaluate the effect of 0.375% FOS on the incidence and level of contamination of *Salmonella typhimurium* on prechilled broiler carcasses. In the first trial, the addition of oligofructose resulted in a significant lower level of contamination of carcasses tested positive for *Salmonella typhimurium,* however, there were no significant differences among treatments in the replicated study. It is possible that higher levels of dietary FOS could be more effective in

reducing Salmonella contamination of broiler carcasses. The researchers concluded that further studies need to be done to elucidate the effects of different sources and levels of fructans on salmonella colonization of caeca and contamination of broilers carcasses.

EFFECT OF DIETARY FRUCTANS ON CHICKEN INTESTINAL MORPHOLOGY

During the immediate post-hatch period intense changes occur in the gastrointestinal system of chicks conditioning efficient digestion and absorption of nutrients from a typical poultry diet. In the first 5-7 days post hatch, the growth of GI tract may be 4-5-fold greater than that of the body, and rapid development of pancreas, liver and small intestine occurs (Nir et al., 1993; Nitsan et al., 1991). The length of villi and microvilli of enterocytes in the small intestine undergoes an enormous increase. Besides, the tremendous growth of the gut mucosa and appearance of the gut-associated lymphoid tissue is observed. Despite the strong genetic determinants in the gut growth, it is clear that dietary factors can have an influence on this early development (Dibner et al., 1996). Additionally, the normal early development of chicken gut is also affected by the presence of intestinal microflora (Cook and Bird, 1973). The intensive growth and maturation of the gut, particularly the small intestine, consumes a substantial part of the available nutrients during the first weeks of life. It is documented that rapidly growing broilers devote about 12% of newly synthesized protein to the digestive tract (Choct, 2009; Xu et al., 2003). Any increase of tissues turnover can additionally enhance the nutrient requirement for maintenance of the luminal tissue at the expense of protein muscle synthesis. It is commonly believed that the structure of intestinal mucosa can provide the information about the health of the digestive tract. Stress factors in the digesta can lead to changes in the intestinal mucosa relatively quickly manifested by a shortening of intestinal villi and deepening of crypts. It is assumed that the increase in the villus height is positively correlated with an increase of the digestive and absorptive function of the intestine due to an increase of the absorptive area, expression of brush border enzymes, and nutrient transport systems (Pluske et al., 1996). In this aspect, the response of the gut to the dietary ingredients (i.e. prebiotics) has an important implication for bird performance.

As shown in animal *in vivo* studies, the influence of inulin-type fructans on gut histomorphology parameters probably occurs through the decrease of the caecal pH and increase of the concentration of the caecal pool of short-chain fatty acids, with a predominance of acetic acid followed by butyrate and propionate (Campbell et al., 1997; Rebolé et al., 2010; Rehman et al., 2008a, 2008b; Roberfroid and Delzenne, 1998). Moreover, dietary fructans can reduce the ammonia concentration in lower segments of the gut through modulation of intestinal microbiota (Rehman et al., 2008a; Yusrizal and Chen, 2003a). These effects are often associated with hyperplasia of the mucosa and increase wall thickness in the small intestine (Oku et al., 1984) and in the caecum (Campbell et al., 1997; Rémésy et al., 1993) accompanied by an increase in blood flow (Rémésy et al., 1993). The results of the studies performed on birds concerning the effects of inulin-like fructans on the gut structure are ambiguous and vary depending mainly on the level of fructans in diets (Table 2). Williams et al. (2008) feeding broiler chickens on mixtures with low level of FOS (0.06% basal diet) did not found any influence of this prebiotic on the gut

morphology (villus height, width and surface) in the duodenum and ileum. Xu et al. (2003) assessed the effects of three levels of dietary fructooligosaccharides added to a broiler basal diet at 2.0, 4.0 and 8.0 g/kg mixture. No dietary effect was detected for villus and microvillus height and crypt depth in the duodenum. Contrary, the villus height was significantly higher in the ileum and the crypt depth in the jejunum and ileum were significantly lower for chicks fed diets with 4.0 g/kg FOS, compared to the control birds. These changes resulted in an increase of ratios of the villus height to crypt depth in the jejunum and ileum. Additionally, supplementation of 4.0 g/kg FOS resulted in elongation of the jejunal microvillus and 2.0 and 4.0 g/kg FOS positively affected the length of ileal microvillus. The level of 8.0 g/kg FOS in the diets had no effect on the gut morphology of broilers. According to the cited authors, these changes are not due to a direct action of fructooligosaccharides on the intestinal tissue but to the ability of FOS to create a favorable intestinal microbial environment. As it was previously mentioned, in broiler chickens fed diets with 4.0 g/kg FOS, but not 8.0 g/kg, the small intestinal and caecal concentration of Lactobacilli and Bifidobacteria increased and the concentration of *E.coli* decreased at the 49th day of age (Xu et al., 2003). The results of studies conducted by other authors also confirm beneficial effects of inulin-type fructans on birds gastrointestinal tract morphology, although in varying degrees. The supplementation of poultry diets with 1% of inulin or oligofructose can lead to an increase of the lengths of small and large intestines in broilers and laying hens (Chen et al., 2005; Yusrizal and Chen, 2003b), elongation of the villus in the chickens jejunal mucosa (Rehman et al., 2007) and increase in the ratio of villus height to crypt depth (Rebolé et al., 2010). Moreover, the villi from inulin and oligofructose treated birds appear to be more dense (Yusrizal and Chen, 2003b) and show a different arrangement of the mucosa (zig-zag arrangement – similar to the wave) (Rebolé et al., 2010). This structure prolongs the contact between the digesta and mucosal epithelium, which could be more effective for nutrient absorption. These beneficial changes in the intestinal mucosa structure may be due to the trophic effect of SCFA, especially butyric acid. It is documented that butyrate is the major intestinal energy source even when other fuel sources (glucose or glutamine) are available and could stimulate the growth of colorectal and ileal mucosal cells (Montagne et al., 2003; Topping and Clifton, 2001). Studies on the effects of inulin-type fructans on the microbial fermentation profile of the broiler GI tract demonstrated that inulin incorporated into the diets in amount of 1 or 2 % elevated the concentration of ceacal digesta butyrate without affecting total SCFA (Rebolé et al., 2010; Rehman et al., 2008a, 2008b). On the contrary, supplementation of chicken diets with oligosaccharides has been reported to enhance both the production of total SCFA as well as the butyric acid concentration (Terada et al., 1994; Zhan et al., 2003). Differences observed in the microbial fermentation profile are probably due to the different rate of microbial degradation of inulin and oligosaccharides in the large bowel (Roberfroid and Delzenne, 1998).

EFFECT OF DIETARY FRUCTANS ON GROWTH PERFORMANCE AND DIETARY NUTRIENT UTILIZATION

Researchers have been concerned over the recent years to find solutions for poultry feeding which support high broiler performance and lower feeding costs. The efficiency of broiler feeding and chicken growth can be determined by the body weight gain, feed conversion ratio and age at slaughter weight. Thus, the importance

of inulin-type fructans in the broilers feeding is appreciated not only from the aspect of poultry health but also in the context of productivity.

In general, the results published on the effect of inulin or FOS on the growth performance of poultry are inconsistent and conflicting under experimental conditions. Some studies indicated a lack of a positive effect of inulin at inclusion from 4.0 to 20 g/kg (Alzueta et al., 2010; Biggs et al., 2007; Rehman et al., 2007) or FOS at concentration from 3.75 to 20 g/kg in the basal diets (Biggs et al., 2007; Patterson et al., 1997; Waldroup et al., 1993) on broilers growth performance. In contrast, other authors have been reported the beneficial effect of inulin-type fructans on broilers growth performance (Ammerman et al., 1988, 1989; Kim et al., 2011; Li et al., 2008; Rebolé et al., 2010; Velasco et al., 2010; Xu et al., 2003; Yusrizal and Chen, 2003b) (Table 3). Ammerman et al. (1988) showed that feeding FOS at 2.5 and 5.0 g/kg basal diet significantly improved feed efficiency and numerically reduced mortality rate of chickens over the entire feeding period of 46 days. They also observed that addition of 3.75 g/kg FOS produced heavier birds at 47 days compared to the control group or to the broilers fed the diet with 7.5 g/kg FOS. Additionally, 3.75 g/kg FOS had positive impact on slaughtering parameters (higher hot carcass weight, percent of breast weight and lower percent of fat pad). Based on these studies (Ammerman et al., 1988, 1989), it appears that lower levels of supplemental oligofructose enhance broiler growth and feed efficiency similar to antibiotic growth promoters, which is in agreement with observations reported by Kim et al. (2011). Xu et al. (2003) found that supplementation of 4 g/kg FOS to the basal mixture significantly increased average daily gain (ADG) of broilers. The addition of 2.0 or 8.0 g/kg FOS had no effect on ADG. Feed intake was unaffected by dietary treatments, but on the other hand, feed conversion ratio (FCR) was improved in the birds fed diets with 2.0 and 4.0 g/kg FOS versus control. The studies performed by Yusrizal and Chen (2003b) indicated that adding of chicory inulin and FOS at 10 g/kg diet improved body and carcass weights, carcass percentage and FCR in female, but not in male broiler chickens. Moreover, it appeared that feeding inulin or FOS resulted in lowering the abdominal fat content in birds. Similarly, Rebole et al. (2010) using inulin at inclusion of 10 g/kg of diet showed its positive effect on male broiler body weight gain (BWG). The higher level of inulin (20 g/kg of diet) had no effect on production parameters. Velasco et al. (2010) observed that the addition of inulin to diets supplemented with two different dietary fat sources (highly saturated palm oil -PO and unsaturated sunflower oil -SO) at 5 g/kg of diet had a better response in BWG than at 10 g/kg of diet. The results of the studies cited above regarding performance parameters suggest that the optimal concentration of FOS supplementation to broiler diets is between 2.5 and 5.0 g/kg and the inulin supplementation should not exceed 10 g/kg mixture. The divergence in productivity response of broilers to dietary inulin-type fructans may be caused by several factors, like type of fructans and their inclusion level, composition of the basal diet, animal characteristics and experimental hygiene conditions (i.e. stress factors) (Hussein et al., 1998; Lan et al., 2007; Patterson and Burkholder, 2003; Van Loo, 2007; Verdonk et al., 2005; Yang et al., 2008).

The beneficial effect of inulin-type fructans on performance parameters, mainly FCR, observed in the studies may be partially explained by the elevated intestinal enzymatic activity under the influence of the fructooligosaccharides. Williams et al. (2008) and Xu et al. (2003) reported that low level (0.6-4.0 g/kg) of FOS increased

the activities of leucine aminopeptidase by 17% in the duodenum and maltase by 24% in the ileum tissue, and significantly improved the activities of total proteases by 27.2% and amylase by 75.2% in the small intestinal digesta of male broiler chickens. The observed effects on the digestive enzymes activities in the small intestine content could be the result of the stimulatory effect of FOS on intestinal microflora, especially *Lactobacillus* and *Bifidobacterium,* that have been reported to deliver enzymes, thus increasing the intestine digestive enzyme activity (Ghadban, 2002; Jin et al., 2000; Sissons, 1989). The higher level of FOS (8.0 g/kg) had no effect on amylase and total protease activity in the broilers GI tract. Moreover, the intestinal lipolytic activities were unaffected by dietary FOS (Xu et al., 2003).

Only few studies have been conducted to investigate the effects of inulin-type fructans on nutrient digestibility. Biggs et al. (2007) examined total tract amino acids (AA) digestibility and ME_n values of diets for male chickens at different ages (3-4, 7, 21 day of age). The results showed that feeding inulin at 8 g/kg diet reduced amino acids total tract digestibility and ME_n concentration in the mixture. Oligofructose, used in the same dose, had no negative impact on AA digestibility at any age. Lowering the amount of inulin and oligofructose from 8 to 4 g/kg diet resulted in the improved ME_n concentration compared to the control birds, but had no effect on AA digestibility. The increase of ME_n probably can be explained by the higher enzymatic activity in the small intestine of chickens (Xu et al., 2003). The results cited above suggest that the low level (4 g/kg) of inulin-type fructans can be fed to broilers with no deleterious effects on ME_n and AA digestibility while the higher level of these prebiotics (8 g/kg) may depress ME_n and AA digestibility (Biggs et al., 2007). In contrast with these findings, Alzueta et al. (2010) observed that inulin at the dose 5, 10, 15 and 20 g/kg diet for broilers had definitely a positive effect on apparent ileal digestibility of: crude protein and most of AA (10 out of 15), crude fat and major fatty acids (palmitic C16:0, oleic C18:1 n-9 and linoleic C18:2 n-6). There was no influence of inulin on starch digestibility and ME_n content in the diets. Differences between the results of experiments conducted by Biggs et al. (2007) and Alzueta et al. (2010) might be due to the method implied in digestibility experiments and to the chickens age. Alzueta et al. (2010) measured the digestibility of nutrients by the ileal method in broilers at 35 day of age, whereas Biggs et al. (2007) used very young birds (up to 21 day) and determined the digestibility of AA by fecal methods. It is documented that dietary inulin increases fecal nitrogen excretion (Roberfroid and Delzenne, 1998) which can be the reason for underestimation of AA digestibility coefficients. This process is the result of *de novo* synthesis of microbial protein derived from the microflora population increase in the presence of fermenting inulin in the large bowel. Moreover, the digestion of all dietary nutrients increases with age in young chicks (Batal and Parsons, 2002; Noy and Sklan, 1997).

The systemic effects of inulin-type fructans in birds have not been widely investigated. Only limited number of studies have been performed on the effects of inulin and FOS on the lipid metabolism in broilers and laying hens (Chen et al., 2005; Velasco et al., 2010; Yusrizal and Chen, 2003b). Yusrizal and Chen (2003b) reported that supplementing diets with inulin or FOS (10 g/kg basal diet) significantly reduced the concentration of serum cholesterol in 35-day-old male (by 46%) and female (by 20 and 25% respectively) broilers. Chen et al. (2005) showed that the addition of FOS and inulin at the level of 10 g of a diet for laying hens significantly reduced blood serum cholesterol by 17.8% and 16.2%, respectively. Additionally, both prebiotics

resulted in the higher cholesterol concentration in the jejunum content as well as in its higher excretion with feaces. The lower concentration of cholesterol in the blood serum of birds and an increase in the cholesterol excretion can be explained by bacterial activity in the small and large bowel. It is demonstrated that *Lactobacilli*, when grow under appropriate conditions (anaerobic condition and presence of bile salts), can assimilate (or uptake) the cholesterol present in the medium or lead to the coprecipitation of cholesterol with the deconjugated bile salts (Gilliland et al., 1985; Jin et al., 1998). Thus, an increase in the cholesterol excretion may be due to the unabsorbable cholesterol in the intestine (Chen et al., 2005). Velasco et al. (2010) showed that the addition of inulin-type fructans could effect lipid metabolism in the liver and change the blood serum metabolites in birds. The researchers found that the addition of inulin at the dose of 5 and 10 g/kg to the broilers diets supplemented with different dietary fat sources linearly reduced the hepatic content of total lipids and total cholesterol (the latter only in the birds fed SO-containing diets) and decreased the concentration of serum triacylglycerol and very low density lipoprotein cholesterol without affecting blood total cholesterol, high- and low-density lipoprotein cholesterol in 34-day-old chicks. Several mechanisms have been proposed to explain the hypotriacylglycerolemic properties of inulin-type fructans in experiments with laboratory animals. One of the accepted hypothesis is that fructans induce a decrease in the hepatic expression and activity of lipogenic enzymes in the liver and reduce *de novo* fatty acids and triacylglycerol synthesis (Delzenne and Kok, 1999; Kok et al., 1996; Roberfroid, 2000). The direct effect of inulin bacterial fermentation products (SCFA) on the modulation of lipoproteins metabolism is not sufficiently clear because short-chain carboxylic acids, in isolation or in mixture, have antagonistic effects on cholesterol metabolism (Roberfroid and Delzenne, 1998). The influence of inulin-type fructans on lipid metabolism in chickens is important not only from the aspect of production effects, but also in the context of quality of products of animal origin. It is commonly known that the dietary fat sources affect the tissue fatty acids (FA) composition but generally, there is a lack of available information regarding the influence of dietary inulin on these parameters. The study conducted by Velasco et al. (2010) showed that inulin supplementation had a beneficial effect on the fatty acids profile of abdominal fat, breast and thigh meat of broilers. The ratio of polyunsaturated fatty acids to saturated fatty acids (PUFA:SFA) in abdominal fat increased when inulin was included in the sunflower oil containing diets. Moreover, the addition of inulin to the experimental diets containing SO caused an increase in PUFA content, PUFA:SFA ratio in the breast and tight meat mainly through the decrease in palmitic acid and the increase in linoleic acid concentration. These results suggest that the beneficial effect of inulin on fatty acids profile depends on the dietary fat source and its degree of saturation (Velasco et al., 2010).

SUMMARY

From a poultry producers and consumers perspective, animal health, performance and production costs, as well as the quality of products of animal origin have the greatest importance. In this context, the role of inulin-type fructans, such as chicory inulin and oligofructose, is considered in poultry feeding. During the last years the number of experiments determining the importance of inulin-type fructans in poultry nutrition has increased. The research results indicate generally a beneficial effect of these prebiotics on microbial community in the gastrointestinal tract, host health (intestinal morphology, reduction of colonization of pathogenic bacteria) and

chickens performance (feed efficiency, body weight gain, nutrients digestibility and absorption, and fat metabolism). Moreover, these additives can be effective in reducing Salmonella contamination of broilers carcasses. The prebiotic effectiveness of inulin-type fructans depends on a number of factors, like the type of supplement (inulin vs. oligofructose), inclusion level, composition of the basal diet, animal characteristics (age, sex, stage of production) and hygienic conditions (i.e. stress factors). Results of studies indicate that inulin and oligofructose may be as effective as antibiotics in the prevention of infections (control of pathogens) and enhancing the productivity of broiler chickens.

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Table 1. Influence of dietary fructans on selected species of intestinal bacteria in male broiler chickens (log cfu/g)

Reference	Treatments	Age	Segment	*Lactobacilli spp.*	*Bifidobacterium spp.*	*E.coli/ coliforms*	*Salmonella spp.*	*Clostridium spp.*
Patterson et al. (1997)	Control	28 d	Caeca	9.56^{a}	8.98^{a}	ND*	ND	6.29
	Kestoses mixture (10%)			10.43^{b}	10.36^{b}	ND	ND	6.00
Xu et al. (2003)	Control	49 d	Small intestine	7.46^{a}	7.22^{a}	7.03^{a}	ND	ND
	FOS (0.4%)			8.47^{b}	8.11^{b}	6.18^{b}	ND	ND
	FOS (0.8%)			8.20^{ab}	7.64^{ab}	6.71^{ab}	ND	ND
	Control	49 d	Caeca	8.42^{a}	8.36^{a}	7.72^{a}	ND	ND
	FOS (0.4%)			9.08^{b}	8.94^{b}	7.17^{b}	ND	ND
	FOS (0.8%)			8.80^{ab}	8.68^{ab}	7.73^{a}	ND	ND
Yusrizal and Chen (2003a)	Control	42 d	Large intestine	9.18	ND	8.85	8.53	ND
	Inulin (1%)			9.35	ND	7.90	8.22	ND
	Oligofructose (1%)			9.22	ND	8.12	7.82	ND
	Control	42 d	Caeca	9.18	ND	7.99	8.26	ND
	Inulin (1%)			9.00	ND	7.96	7.79	ND
	Oligofructose (1%)			9.32	ND	7.65	7.86	ND
Biggs et al. (2007)	Control	21 d	Caeca	9.39	9.12	9.59	ND	8.44
	Inulin (0.4%)			9.28	9.26	9.73	ND	8.46
	Oligofructose (0.4%)			9.10	9.12	9.51	ND	8.40
Rebolé et al. (2010)	Control	35 d	Ileum	7.24^{a}	6.25^{a}	ND	ND	ND
	Inulin (1%)			7.48^{a}	6.50^{a}	ND	ND	ND
	Inulin (2%)			8.21^{b}	7.03^{b}	ND	ND	ND
	Control	35 d	Caeca	8.33^{a}	8.04^{a}	ND	ND	ND
	Inulin (1%)			8.80^{b}	8.30^{ab}	ND	ND	ND
	Inulin (2%)			9.03^{b}	8.58^{b}	ND	ND	ND

*ND- not determined; ^{ab} denote differences ($p<0.05$)

Table2. Influence of dietary fructans on selected parameters of intestinal morphology of broiler chickens

Reference	Treatments	Age	Segment	Villus height (µm)	Crypt depth (µm)	Villus height : Crypt depth	Microvillus height (µm)
Xu et al. (2003)	Control	49 d	Duodenum	674.1	481.5	1.40	1.96
	FOS (0.4%)			688.2	498.7	1.38	2.12
	FOS (0.8%)			670.3	482.3	1.39	2.06
	Control	49 d	Jejunum	780.5	530.9^{a}	1.47^{a}	2.15^{a}
	FOS (0.4%)			814.7	441.2^{b}	1.85^{b}	2.61^{b}
	FOS (0.8%)			803.0	499.3^{ab}	1.61^{ab}	2.43^{ab}
	Control	49 d	Ileum	541.2^{a}	436.4^{a}	1.24^{a}	1.40^{a}
	FOS (0.4%)			625.4^{b}	325.3^{b}	1.92^{b}	1.94^{b}
	FOS (0.8%)			570.1^{ab}	389.4^{ab}	1.46^{a}	1.54^{a}
Rehman et al. (2007)	Control	35 d	Jejunum	781.6^{a}	199.3^{a}	3.94	ND*
	Inulin (1%)			941.2^{b}	260.5^{b}	3.63	ND
Williams et al. (2008)	Control	21 d	Duodenum	1548.0	118.0	13.21	ND
	FOS (0.06%)			1441.0	121.0	12.05	ND
	Control	21 d	Ileum	420.0	102.0	4.15	ND
	FOS (0.06%)			445.0	105.0	4.31	ND
Rebolé et al. (2010)	Control	35 d	Jejunum	1141.0	133.0^{ab}	10.86^{a}	2.25
	Inulin (1%)			1498.0	126.0^{a}	12.44^{b}	2.06
	Inulin (2%)			1471.0	144.0^{b}	10.57^{a}	2.06

*ND- not determined; ^{ab} denote differences ($p<0.05$)

Table 3. Influence of dietary fructans on growth parameters in broiler chickens

Reference	Treatments	Sex	Age	Body weight gain (g/bird)	Feed intake (g/bird)	Feed conversion (feed:gain)
Waldroup et al. (1993)	Control	both sexes	49 d	2,242.0	-	1.97
	FOS (0.375%)			2,294.0	-	1.94
Yusrizal and Chen (2003b)	Control	females	42 d	1,972.8[a]	-	1.93[a]
	Inulin (1%)			1,986.5[a]	-	1.95[a]
	Oligofructose (1%)			2,176.2[b]	-	1.78[b]
Alzueta et al. (2010)	Control	males	35 d	1,716.0	2,631.0	1.53
	Inulin (0.5%)			1,750.0	2,677.0	1.53
	Inulin (1%)			1,725.0	2,659.0	1.53
	Inulin (1.5%)			1,756.0	2,650.0	1.51
	Inulin (2%)			1,735.0	2,667.0	1.54
Rebolé et al. (2010)	Control	males	35 d	1,529.0[a]	2,500.0	1.64
	Inulin (1%)			1,638.0[b]	2,655.0	1.62
	Inulin (2%)			1,600.0[ab]	2,583.0	1.62
Kim et al. (2011)	Control	both sexes	28 d	1,348.2[a]	2,191.8	1.62
	FOS (0.25%)			1,384.8[b]	2,230.7	1.61
	FOS (0.5%)			1,343.3[a]	2,191.4	1.62

[ab] denote differences ($p<0.05$)