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Fiber as a prebiotic for poultry: a review

Fibra como prebiótico para aves de producción: una revisión

Sánchez-Torres Laura[1] ID*, Macias-Flores Mario[1] ID, Gutiérrez-Arenas Diana[2] ID, Arredondo-Castro Mauricio[2] ID, Valencia-Posadas Mauricio[2] ID, Avila-Ramos Fidel[2] ID**

[1]Maestría en Producción Pecuaria; Universidad de Guanajuato, Campus Irapuato-Salamanca, División Ciencias de la Vida. México. [2]División Ciencias de la Vida, Universidad de Guanajuato, Programa Educativo de Medicina Veterinaria y Zootecnia. México. *Responsible author: **Author for correspondence: Avila-Ramos Fidel, Programa Educativo de Medicina Veterinaria y Zootecnia, Ex Hacienda El Copal km. 9; carretera Irapuato-Silao; A.P. 311; C.P. 36500; Irapuato, Guanajuato. México. E-mail: ledifar@ugto.mx, sanchez.torres122@outlook.com, ma.maciasflores@ugto.mx, diana.gutierrez@ugto.mx, arredondo.m@ugto.mx, mauvp001@yahoo.com.mx

ABSTRACT

The review was elaborated to know the effect of fiber used as a prebiotic in broilers and laying hens. A review was made on generalities of fiber and its benefits on immunity, digestive development, nutrient digestibility and productive performance. It was found that fiber as an additive can be included at levels lower than 3% to improve the immune response of birds, increase the development of intestinal villi and the amount of cytokines that regulate chemotaxis, limiting the permeability of toxic substances to the bloodstream, and regulate the inflammatory response of the intestine. Fiber stimulates the intestinal microbiota by preventing the adherence and development of pathogenic bacteria, as well as the production of antimicrobial peptides. In addition, fiber can regulate intestinal motility, general microbiota, lipid accumulation in the liver, lower cholesterol, contribute to liver function, reduce pollutant emissions to the environment and improve nutrient absorption. Therefore, fiber can improve weight gain, feed conversion and gizzard muscle development. It is concluded that fiber, as a prebiotic can be included in the poultry diet to replace synthetic additives to increase the productive performance of poultry.
Keywords: Intestinal health, functional feed, phytobiotics in poultry, natural additive.

RESUMEN

La revisión fue elaborada para conocer el efecto que tiene la fibra usada como prebiótico en pollo de engorda y gallinas de postura. Se realizó una revisión sobre las generalidades de la fibra y los beneficios que aporta sobre la inmunidad, desarrollo digestivo, digestibilidad de los nutrientes y rendimiento productivo. Se encontró que la fibra como aditivo se puede incluir a niveles menores del 3% para mejorar la respuesta inmune de las aves, aumenta el desarrollo de vellosidades intestinales y la cantidad de citoquinas reguladoras de la quimiotaxis limitando la permeabilidad de sustancias tóxicas al torrente sanguíneo, además, regula la respuesta inflamatoria del intestino. La fibra estimula el microbiota intestinal evitando la adherencia y desarrollo de bacterias patógenas, así como la producción de péptidos antimicrobianos. Además, la fibra puede regular la motilidad intestinal, la microbiota general, la acumulación de lípidos en hígado, disminuir el colesterol, contribuir al funcionamiento hepático, disminuir emisiones contaminantes al ambiente y mejorar la absorción de los nutrientes. Por lo tanto, la fibra puede mejorar la ganancia de peso, la conversión del alimento y el desarrollo muscular de la molleja. Se concluye que la fibra como prebiótico puede ser incluida en la dieta de las aves para sustituir a los aditivos sintéticos para incrementar el rendimiento productivo de las aves.
Palabras clave: Salud intestinal, alimento funcional, fitobiótico en aves, aditivo natural.

INTRODUCTION

Poultry for meat production is characterized by reaching their ideal weight in a few weeks with proper management and care of gut health (Sugiharto, 2016; Celi *et al*., 2017; Kogut, 2018; Jha *et al*., 2019). When developing a diet, appropriate ingredients should be included to protect the mucosa, microbiota and maintain homeostasis of the digestive system. Otherwise, enteric disturbances occur leading to increased production costs caused by the cost of treatments and mortality in birds (Tahergorabi *et al*., 2015; Mahmood & Guo, 2020).

An alternative to promote the intestinal health of poultry is to add fiber as a functional additive to the diet, adding fiber in doses lower than 3% can favor the maturation of the immune system, the microbiota development of the digestive tract and the morphology of intestinal structures (Hetland *et al*., 2004; Hetland *et al*., 2005; Das *et al*., 2012). Mendoza-Ávila *et al*. (2020) describe fibers contained in feeds and show evidence of their nutraceutical properties. Nutritional management of poultry with phytobiotics can displace the use of synthetic additives, reduce residues in meat and the environmental impact caused in production units (Das *et al*., 2012; Sittiya *et al*., 2020; Mendoza-Ávila *et al*., 2020).

The European Union has restricted the addition of antimicrobials as growth promoters in the poultry industry without negative effects since 2006. The Food and Drug Administration (FDA) banned the use of these compounds in products intended for human consumption in the United States as of 2017 and the Secretariat of Agricultural Defense (SDA) in Brazil as of 2018. Measures used by governments stimulate research on natural ingredients making fiber a natural prebiotic alternative in poultry nutritional management (Kridtayopas *et al*., 2019).

Currently, there is controversy about adding fiber, the type and amount of fiber to poultry diets because research reports are inconclusive about its effects on the poultry body. The general benefits of fiber have been mainly related to the immune system and development of the digestive tract: intestinal villi size, intestinal microbiota and its mucosa (Kogut, 2018). Therefore, the aim of the research is to describe the benefits of fiber as a prebiotic and its ability to protect intestinal health in poultry.

Fiber

Fiber is defined as the sum of plant cellular components that cannot be degraded by digestive enzymes in monogastrics (Hetland *et al*., 2004). According to the structure, their configuration and size of the carbohydrates that compose them; fibers can be classified into oligosaccharides and polysaccharides (Makki *el at*., 2018). Oligosaccharides are made up of chains of 3 to 10 monosaccharides, on the other hand, polysaccharides such as cellulose are made up of multiple units. Hemicellulose, inulin, pectin, gums, mucilages and beta-glucans have similar structures, surrounding the cellulose and hemicellulose microfibrils is lignin which is a structural polymer (Krás *et al*., 2013; Segura *et al*., 2007).

Fiber is classified according to its degree of water solubility as soluble fiber and non-soluble fiber, soluble fibers retain water producing viscous solutions, the higher the solubility of the fiber the more fermentable it is. Lignin is the intracellular part of fibrous cells that encloses soluble carbohydrates and is used to determine the amount of fiber in a food (Segura *et al*., 2007). In the laboratory, neutral detergent fiber can be measured which is the partially digestible portion of the fiber (NDF): lignin, cellulose, and hemicellulose, as well as acid detergent fiber (ADF) and crude fiber (CF): lignin and cellulose which indicate the non-digestible fraction of the feed (Segura *et al.*, 2007). Fibers can also be separated into components to recognize their individual properties.

Fibers found in poultry feed ingredients differ in their composition, abundance and in the nutritional value, they contribute to the diet, they are not fully known because fiber has been considered as a negative ingredient for poultry (Makki *et al*., 2018). However, the characteristics of fibers depend mainly on their plant origin (Krás *et al.*, 2013). In monogastrics, fiber modifies the passage of feed in the intestine, the digestion of nutrients and the gut microbiota in general (Zaefarian *et al.*, 2015).

Fiber digestion

During the digestive process birds secrete amylase enzymes to degrade simple carbohydrates, but they cannot hydrolyse β1-4 bonds of polysaccharide fiber, therefore, the fiber will reach the gut intact (Krás *et al.*, 2013; Zaefarian *et al*., 2015; Mohanty *et al*., 2018; Raza *et al*., 2019). In this body region, anaerobic bacteria attach themselves around the fiber, feed on it and multiply (Mahmood & Guo, 2020). The reproducing bacterial colonies secrete enzymes β-glucuronidase, β-glucosidase and β-mannanase capable of breaking glycosidic bonds to ferment fibre producing organic acids, amino acids, purines and pyrimidines (Das *et al*., 2012; Makki *et al*., 2018). Cecal digestion in poultry is a process where bacterial fermentation of fibre occurs. Cecal development in poultry is directly related to feeding; in some cases, they can have a histological development similar to the intestine Adebowale *et al*., 2019).

During fiber fermentation different metabolites are produced which vary depending on the type of bacteria (Mohanty *et al*., 2018). In the case of *Streptococcus* and *Lactobacillus* lactic acid is obtained, *Enterobacter* produces acetic and formic acid, *Clostridium* and *Corinebacterium* propionic, acetic and succinic acid. While *Escherichia coli*, *Salmonella*, *Shigella* and *Proteus* generate gases such as H_2 and CO_2 that alter digestive physiology and host welfare (Makki *et al*., 2018). In poultry, the efficiency of bacteria to degrade fiber depends on its solubility, its size, the polymerization carbohydrate degree, the availability of the substrate in the medium and the ability of microorganisms to bind to it (Cardoso *et al.*, 2020; Mahmood & Guo, 2020).

Gut health

The gut is the site where digestion takes place and it is responsible for absorbing nutrients through a capillary network that transports them to the portal circulation (Kogut, 2018). Along this organ there is gut-associated lymphoid tissue (GALT) formed by Peyer's patches and cecal tonsils where T-lymphocytes mature. In the lamina propria there are macrophages, granulocytes and lymphocytes fulfilling their function of local immunity (Kogut *et al*., 2018).

The intestine has villi formed by epithelial folds that project into the lumen increasing the absorptive surface of enterocytes. The villous surface is formed by mucin-secreting Goblet cells; between each villus are formed Lieberkuhn's crypts, which have Paneth cells, secreting antibacterial substances, (Kogut *et al*., 2018). Epithelial cells in addition to fulfilling their structural function secrete cytokines that regulate the chemotaxis of the

GALT system to present selective permeability that limits the absorption of toxic substances with high regenerative capacity (Chassaing *et al*., 2014; Kogut *et al*., 2018).

The epithelial cell membrane has TLR (Toll-like receptor), NLR (nucleotide oligomerisation domain-like receptor) and PRR (pattern recognition receptors) receptors that respond to stimuli from LPS (lipopolysaccharide) or bacterial endotoxins and certain dietary components (Kogut *et al*., 2018). When receptors recognize stimuli, they initiate the secretion of cytokines TNF-α, IL-6, IL-1β activating the GALT system (Chassaing *et al*., 2014; Mahmood & Guo, 2020). However, intestinal macrophages react to TLR receptor stimulation by secreting IL-10 as an anti-inflammatory that normally regulates the inflammatory response (Chassing *et al*., 2014; Kogut *et al*., 2017).
Rapid growth of birds, excess nutrients in diets, injuries in the digestive tract and constant exposure to LPS can cause chronic inflammation in their gut (Kogut, 2017). Therefore, the function of the digestive tract decreases, it remains in a state of oxidative stress and immune incompetence occurs (Cardoso *et al*., 2020). The balance between diet, mucosa and gut determines gut health (Jha *et al*., 2019); its neglect increases the bird's susceptibility to inflammation or infection by pathogenic bacteria (Mahmood & Guo, 2020). In addition, each villus is lined with microorganisms that help maintain intestinal homeostasis; these populations vary according to the age of the host, the diet administered, the use of antimicrobials and even the digestive enzymes themselves (Clavijo & Vives, 2018; Szychlinska *et al*., 2019). The expression of proinflammatory cytokines can antagonize growth hormone, increase the amount of glucocorticoids in the blood and alter osteogenesis in birds (Tong *et al*., 2020).

The intestinal microbiota
Bacteria of the genera Firmicutes (70%), Bacteroides (12.3%), dominate a microbial community *Proteobacteria* (9.3%) and others (8.4%) that line the gastrointestinal tract (Kogut, 2018). Particularly bacteria of the species *Lactobacillus*, *Enterococcus* and *Clostridium* predominate, but the cecum has the largest population (Chen *et al.*, 2020). However, species pathogenic to birds and bacteria of zoonotic public health concern such as *Campylobacter jejuni*, *Salmonella enterica*, *Escherichia coli* and *Clostridium perfringens* also inhabit the cecum (Clavijo & Vives, 2018).
The resident microbiota excludes pathogenic bacteria that compete for nutrients and act as a defensive barrier preventing the adherence of other bacterial species. In addition, antimicrobial peptides are produced and stimulate their production by the host (Adebowale *et al*., 2019; Mahmood & Guo, 2020; Van der Wielen *et al.*, 2000). The gut microbiota functions as a metabolic organ that can be compared to the liver; it mainly hydrolyses polysaccharides and produces short-chain fatty acids such as acetate, butyrate, succinate and propionate (Chassaing *et al*., 2014; Adebowale *et al*., 2019; Van der Wielen *et al.*, 2000).
In the intestine, short-chain fatty acids freely enter enterocytes producing energy that promotes epithelial and intestinal mucosal development (Kogut, 2018; Adebowale *et al*., 2019). Butyrate and acetate stimulate goblet cells to regulate mucin secretion (Makki *et al*., 2018). Resident bacteria are not recognized as foreign agents because they cover TLR receptors by preventing their activation, thus moderating the inflammatory response. In case of receptor activation, the $CD4^{+}$ T-cell response is stimulated (Chassaing *et al*.,

2014; Clavijo & Vives, 2018). Furthermore, chain fatty acids generated by bacterial synthesis have been reported to participate in the gut-brain pathway because they serve as energy for astrocytes, thereby regulating appetite and can be transformed to glucose in the liver, decreasing cholesterol synthesis (Hu *et al*., 2018).

Fermentation of fibers releases phenolic compounds; secondary metabolites such as terpenes, phenols and flavonoids, phytochemicals that have antioxidant or anti-inflammatory effects with local or systemic benefits to the host (Makki *et al*., 2018; Gasaly *et al*., 2020). On the other hand, intestinal bacteria synthesise vitamins such as biotin or vitamin K, which are useful for the organism, and even bacteria themselves can be a source of amino acids (Chassaing *et al*., 2014; Clavijo & Vives, 2018). In dysbiosis, pathogenic bacteria proliferate causing enteric infections, thus decreasing growth rates and increasing mortality (Kogut, 2018), while their balance can reduce glucocorticoid secretion in birds under stress and involve bacterial metabolites in fatty acid biosynthesis (Kridtayopas *et al*., 2019; Chen *et al*., 2020).

The microbiota can be modified by diet, sex, environmental conditions, age, even animal bedding. Therefore, its regulation is promoted at specific times such as at hatching, during feed changes and in the course of enteric diseases (Clavijo & Vives, 2018; Kogut *et al*., 2018). The aim is to improve production parameters by modulating the inflammatory response, avoid pathogen colonization and prevent disease in both animals and consumers (Kogut, 2018). To this end, the use of essential oils, bacteriophages, bacteriocins, enzymes, functional feeds, probiotics, prebiotics and synbiotics as well as physical feed modification have been suggested (Clavijo & Vives, 2018; Kogut, 2018; Kheravii *et al*., 2018; Chen *et al*, 2020).

Use in monogastrics

The use of dietary fiber in monogastrics has been investigated, showing that its consumption can regulate intestinal motility, modulate the intestinal microbiota, prevent lipid accumulation in the liver, lower blood glycemic index, regulate liver function, prevent colon cancer and improve intestinal mineral absorption capacity (Makki *et al*., 2018). Due to the evidence obtained and its biological effect, fiber is recognized as a functional food (Das *et al*., 2012).

In livestock production, fiber is being investigated in an attempt to replace synthetic ingredients. In addition, fiber can be an alternative to reduce pollutant emissions from the poultry industry into the environment (Sittiya *et al.*, 2020). Due to the advantages of fiber when used in the development of the digestive system, it has been sought to understand its energy potential and effect on the digestive process in pigs and poultry (Hetland *et al.*, 2005). Fiber combination with another additive has improved weight gain, feed intake, feed conversion, egg production, egg weight and egg size in laying hens. In addition, it has health effects by lowering blood cholesterol levels (Tang *et al*., 2017). In rats, soluble and insoluble prickly pear cactus (Nopal) fiber allows greater bioavailability of calcium in the diet, improving bone density (Mendoza-Ávila *et al*., 2020).

Prebiotics

These are additives made up of fibers that are resistant to the enzymatic action of monogastrics but degradable by intestinal microorganisms (Mohanty *et al*., 2018). As substrates for bacterial fermentation, they act as competitive exclusion products

promoting the proliferation of beneficial bacteria in the gut by inhibiting the growth and adhesion of harmful bacteria (Clavijo & Vives, 2018). These compounds can also increase intestinal osmosis by enhancing nutrient absorption (Kridtayopas *et al*., 2019).
The use of prebiotics in production units is limited compared to other options used to regulate the intestinal microbiota in poultry (Clavijo y Vives, 2018). Therefore, it can be used as an alternative to decrease the use of antibiotics, reduce residues in products for consumption and in the environment (González & Ángeles, 2017). However, it should be mentioned that the morphological and physiological changes in the digestive tract of chicken depend on the type and components of fiber added as a prebiotic, as well as its solubility.
It has been determined that the prebiotics with the highest digestibility are isomalt oligosaccharides (IMO), galacto oligosaccharides (GOS) and fructooligosaccharides (FOS) to stimulate *Lactobacillus* reproduction (Kridtayopas *et al*., 2019; Karimian & Rezaeipour, 2020). Its administration decreases the negative effects caused by *Escherichia coli* by increasing the population of *Enterococcus* and *Lactobacillus* (Tarabees *et al*., 2019; Karimian & Rezaeipour, 2020). It also decreases the presence of *Campylobacter* in the cecum, reducing the risk of contaminating food, as well as the prevalence of poultry foodborne diseases (Froebel *et al*., 2019).
Studies on the addition of fiber in poultry are limited, but there is research on its immunostimulatory effect by increasing vaccine titres against Newcastle virus disease and the amount of IgY in serum (Mohammed *et al*., 2016). It has been reported that administration of prebiotics *in ovo* can favour gene expression to resist heat stress conditions (Slawinska *et al*., 2019).

Symbiotics

Symbiotics are characterised by the combination of two or more functional additives that allow them to enhance their performance for either or both ingredients. As an example, the combination of prebiotic agents is used to aid growth (Mohanty *et al*., 2018). In addition, they are natural beneficial residents of the gut microbiota with various health benefits. Likewise, probiotics must have the ability to colonise, adhere and reproduce on epithelial cells in the host, survive gastric acidity and bile secretions (Clavijo y Vives, 2018).
The combination of these two agents has potentiated the beneficial effect of each (Awad *et al*., 2009; Mohanty *et al*., 2018). There is evidence that the use of synbiotics reduces the amount of *Escherichia coli*, *Clostridium perfringens*, *Campylobacter jejuni* and *Salmonella* spp (Kridtayopas *et al*., 2019). In addition, it can increase post-vaccination Newcastle titres, improves bone density, and promotes growth of intestinal villi in poultry (Kridtayopas *et al*., 2019). Under stressful conditions, symbiotics can improve the productive variables of animals (Kridtayopas *et al*., 2019).

Digestive system development

In laying hens, insoluble fiber accumulates in the gizzard increasing feed retention, moderating feed flow and improving muscle development, similar effect of fiber in broilers at 21 days of feeding 2.5 and 3% insoluble fiber allows small intestine development and reduces gizzard pH (Hetland *et al.*, 2004; Amerah *et al*., 2009). Muscle development of

the gizzard is related to fiber particle size, which can facilitate gastroduodenal reflux and improve the contact of digestive enzymes with the feed (Jiménez-Moreno *et al*., 2019).
It has been reported that in diets with high amounts of soluble fibre *Clostridium perfringens* proliferates causing necrotic enteritis and in turn decreases oxygen tension in the gut favouring the development of toxin-producing anaerobic bacteria (Clavijo & Vives, 2018; Raza *et al*., 2019). In a study by Van der Wielen *et al.* (2000) indicate that enterobacteria are susceptible to the amount of acetate, propionate and butyrate in their environment, while lactobacilli are not affected.

Intestinal viscosity

Cardoso *et al.* (2020) report that high amounts of fiber increase intestinal viscosity decreasing the diffusion of digestive enzymes and the digestibility of nutrients contained in the feed (Krás *et al.*, 2013; Raza *et al*., 2019). In addition, increasing intestinal transit decreases feed intake and weight gain in poultry (Cardoso *et al.*, 2020). However, there are contrary observations where the administration of fiber decreases the transit speed in the digestive tract, producing an increase in feed intake due to energy dilution resulting from viscosity and when the amount of fiber is high the effect is the opposite due to the volume administered (Krás *et al.*, 2013).

Digestibility of nutrients

Raza *et al*. (2019) reported anti-nutritional effect of soluble fiber due to thickening of the gut mucosa, which decreases digestion. The type of bird, its age and fiber type can influence this variable (Eggum, 1995). Donadelli *et al*. (2019) reported different results where there was no effect on the productive parameters of birds, but nutrient digestibility increased. There are reports that indicate that adding 3% insoluble fiber increases the availability of metabolizable energy in broiler diets because it improves starch digestion and in laying hens it improves mineral digestibility (Amerah *et al*., 2009; Donadelli *et al*., 2019; Jiménez-Moreno *et al*., 2019).

Productive yield

The administration of soluble and insoluble fiber has been reported to decrease feed intake and weight gain in broilers, an effect associated with insoluble fiber (Krás *et al*., 2013; Leung *et al*., 2018; Raza *et al*., 2019). On the other hand, it has been described that administering fiber improves carcass yield (Tarabees *et al*., 2019; Adewole *et al.*, 2020), increases weight gain at 21 days. Combining fiber with mannan oligosaccharides (MOS) and enzymes increases weight gain (Karimian & Rezaeipour, 2020); and even in birds challenged with *Escherichia coli* O78:H11 improves weight gain and decreases mortality (Tarabees *et al*., 2019). Hetland *et al.* (2005) report that laying hens seek fiber when feather pecking or ingesting litter to compensate for the lack of this ingredient in diets.

CONCLUSIONS

Fiber can be used as a prebiotic in poultry feeds due to its potential health benefits. Studies on the amounts fed to feed are needed to identify its effect on digestive system development, microbiota and immunity in birds of different ages and species.

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Errata Erratum

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