GUT MICROBIOTA MODULATION FOR ENHANCED POULTRY PRODUCTION

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Abstract

The poultry gastrointestinal tract (GIT) being rich in diverse microbial community is considered to be effective in optimal nutrient digestion, absorption, immunity development and disease resistance. Gut microbiota varies between poultry flocks due to different factors. The factors may be categorized as extraneous factors like feed, water, environment and host associated factors like breeder's nutrition & health, hatchery conditions, brooding conditions etc. Modulation of gut microbiota by nutrients and alternative gut health additives gives better impetus to gut protection, host immunity and production performance. Although it has been observed that the association of gut microbiota and productivity of poultry is quite close, specific gut microbial population is yet to be identified that may be exploited to enhance productivity.

Key words: Gastrointestinal tract, Gut, Microbiota, Poultry production

Introduction

As a source of safe and quality protein in human nutrition, poultry meat and egg production are considered precious throughout the world (Shang *et al.*, 2018). By 2050, the world population is expected to touch about 9.6 billion (Borda-Molina *et al.*, 2018). To match the demands of a growing global population, the production of chicken meat and egg are showing exponential growth. Such bumper growth of poultry production is only possible with proper disease prevention strategy. Gut health is the key to optimize nutrient digestion and absorption, immunity development and disease resistance. Several factors viz. the environment, feed and the gastrointestinal microbiota have got impact on the gut integrity and gut health (Shang *et al.*, 2018). Immediately after hatch, the chicken

gastrointestinal tract (GIT) being exposed to exogenous microorganism becomes a natural habitat of a wide array of microbiota (Pan and Yu, 2014). The age of the birds, location in the digestive tract and diet are considered as reasons for the diversity of the chicken gut microbiota (Shang *et al.*, 2018). To understand the impact of gut microbiota on intestinal health and productive performance of the poultry birds an attempt has been made to review the existing literature on the subject and to prepare a scientific compilation based on the surveyed studies.

Chicken gut microbiota and its role

The chicken GIT contains a complex microbial community (bacteria, fungi, protozoa and viruses) that are dominated by bacteria (Shang

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et al., 2018). An optimal composition of gut microbiota requires for optimal digestion, nutrient absorption, immunity development, better feed conversion and animal performances. The gut microbiota attaches with the epithelial layer of gut forming a protective shield, thereby, reducing the chance for the colonization of pathogenic bacteria (Yegani and Korver, 2008). More than 900 bacterial species are found to inhabit the gut of broiler (Borda-Molina *et al.*, 2018). These bacteria produce vitamins, short chain fatty acids, organic acids, antimicrobial compounds and lower triglyceride. Moreover, they induce non-pathogenic immune responses. By this way they provide both nutrition and protection for the animal (Apajalahti, 2005; Yegani and Korver, 2008). It has been noted that, birds that lack gut microbiota are prone to develop disease due to poor immunity (Bailey, 2019). Birds can't digest plant fibers. With the help of gut microbiota this problem can be resolved. It can enhance the growth and production of poultry by producing extra nutrients through the fermentation of the plant fibres (Yadav and Jha, 2019).

Factors influencing modulation of the gut microbiota

I. Extraneous factors

Feed: The dietary components escaping host digestion and absorption serve as the substrate for the growth on intestinal bacteria. This implies that feed has got influence on the growth of gut microbiota in poultry (Pan and Yu, 2014). In reality, the balance of gut microbiota is influenced by raw ingredients, nutrient density and the form of the feed. High levels of indigestible, water-soluble non-starch polysaccharides (NSPs) in the feed can increase viscosity in the gut, decreased digesta passage rate, and a decline in nutrient digestibility which in turn favors the growth of *C. perfringens*. This may encourage necrotic enteritis in chicks (Timbermont *et al.*, 2011). The risk of bacterial

enteritis can be reduced if we add exogenous NSPase enzyme in feed. The source and level of dietary protein may also affect gut microbiota. Diets with high levels of anti-nutritional factors in the feed could lead to poor digestibility, resulting in more undigested protein in the intestinal lumen. The presence of undigested protein in the lumen favors the proliferation of pathogenic bacteria, such as *C. perfringens* (Drew *et al.*, 2004). Supplementing the diet with good quality exogenous protease enzyme has been shown to considerably improve protein digestibility. In addition, dietary fat source has got effect on gut microbiota. This is supported by the report that *C. perfringens* was more abundant in the ileum of broiler chickens fed diet with animal fat than chickens fed diet with soy oil (Knarreborg *et al.*, 2002). It has been observed that high level of calcium in diet for each age group and productive phase may be deleterious to intestinal health. Calcium may chelate nutrients, reduce enzyme activity, and thereby, promoting proliferation of *C. perfringens* (Paiva *et al.*, 2013). Alteration of the normal gut functions such as barrier function and nutrient absorption was observed by the presence of feed contaminated by mycotoxins (Grenier and Applegate, 2013). Adding a broad-spectrum mycotoxin binder to the diet can reduce the adverse effect on mycotoxins on poultry health.

Water: Water quality and water line management are essential for long term gut health benefits and bird's performance. Water quality depends upon water source, water hardness, water pH and mineral contents in water (Bailey, 2019). Contaminated water with microorganisms is relatively common and has adverse effects on normal functioning of gut health and bird's performances. Water pH is a key factor that can influence microbial populations in water and in the gut, thus maintaining balance of gut microbiota. The water pH should be maintained between 5 to 7 because alkaline pH is shown to

reduce the activity of digestive enzymes (Oviedo-Randon, 2019). Some studies showed that birds can tolerate a low pH of 3.5 (Abrigo, 2019). Acidic water is unpalatable, while alkaline water obstructs watering systems by depositing excessive mineral, viz. calcium and magnesium. Water outside maximum acceptable levels for both pH and hardness can create an environment for biofilms and endotoxins to thrive in the water system due to the proliferation of algae and microbes and negatively impacts on bird's performance.

Environment: The local climate in a poultry house is an important factor for poultry performances. The age, phase of production, size of the birds and external environmental conditions, viz. optimum temperature, air velocity and relative humidity are considered vital for poultry health and productivity (Kocaman *et al.*, 2006). The gut microbiota of poultry profiles varies as per the regional and seasonal climatic conditions (Zhou *et al.*, 2016). Feed intake patterns and intestinal motility of poultry may be changed due to different environmental stress factors, viz. heat, cold, humidity and drought. It may cause reduced digestion and poor gut health (Wilson *et al.*, 1980).

II. Host associated factors

Breeder's nutrition and health: For proper development of their progeny, optimum nutrition of the breeder birds is necessary (Calini and Sirri, 2007). Egg nutrients obtained from hen are considered to be important for embryonic development. Nutrients viz. vitamin D, trace minerals, carotenoids, and fatty acids have got tremendous effects on gut, and of course, on its immunity development (Calini and Sirri, 2007; Leandro *et al.*, 2011a,b; Oviedo-Rondón *et al.*, 2013). Breeder hens can transfer good and bad intestinal microbes and immunity to their progeny (Inoue *et al.*, 2008; Leandro *et al.*, 2011a,b). Intestinal commensals and pathogens can be acquired in the

pre-hatching phase, directly from the oviduct of the hen (Gantois *et al.*, 2009) or from the environment through the pores in the eggshell. The gut microbiota composition may also be influenced by maternal antibodies. Maternal immunity can provide protection in chicks against enteric pathogens until 14 days of age (Grindstaff *et al.*, 2003; Hamal *et al.*, 2006).

Hatchery conditions: The high hygiene levels of hatcheries influence the development of the GIT and immune system. Some literature reported that increased incubation temperatures reduced enzymatic activity and the relative sizes of the pro-ventriculus, gizzard and intestine (Wineland *et al.*, 2006a,b; Leksrisonpong *et al.*, 2007). High incubation temperature induces digestive capacity of the chicks creating more problems of intestine (Smith, 2011). Suboptimal incubation increases hatching window, some chicks to hatch either too early, 36-48 h before pulling chicks out of hatchers, or too late. However, neither of the conditions is suitable for proper development of the gut associated lymphoid tissue (GALT) and general immunity (Shira *et al.*, 2005).

Brooding conditions, farm management and biosecurity: Brooding management, overall farm management and biosecurity are key factors to maintain gut health and performances (Bailey, 2019). In poultry, production performance, overall health and disease resistance are dependent on the initial development of intestinal microbiota. For proper development of the gut tissues, immune system and microbiota, early access to feed, water and optimal brooding conditions are required. Delayed responses in terms of all immunity parameters are observed in the caeca and colon and on the colonization of lymphocytes in the bursa when the birds are exposed to feed and water after 48 hours of hatching (Shira *et al.*, 2005). This will lead to improper immune activity during the first two

weeks of life. During this period, most prime vaccines are administered, and chickens are exposed to potential enteric pathogens. Good house ventilation, litter management, proper stock density and lighting programs plays a vital role to maintain the balance of gut microbiota (Dawkins *et al.*, 2004; Olanrewaju *et al.*, 2006; Dunlop *et al.*, 2016; Wang *et al.*, 2016). While providing feed and vaccine, composition of gut microbiota varies. In this situation, provision of sub-optimal management may lead to bacterial enteritis. To have a positive impact on gut health and development of poultry, proper hygienic conditions including bio-security measures are to be followed strictly (Bailey, 2019).

Litter microbiota: Chickens are raised on litter made of pine shavings, rice hulls and other vegetal materials. Many a times, feed, water, and chicken excreta are mixed and composted with the bedding materials. The materials thus produced may sometimes be responsible for changing the contents and characteristics of gut microbiota (Wang *et al.*, 2018). During their growth phase, chicken acquire litter microbes by picking and ingesting litter materials that form a part of its gut microbiota. On the other hand, from faecal matter of birds litter get a unique colony of microbiota with diversified forms (Pan and Yu, 2014). A close correlation between caecal and litter microbiota was observed with similar type of patterns of microbes is during seasonal variation and environmental conditions in a 1 year long study (Diaz Carrasco, 2019). The load of gut microbiota remaining higher in reused litter and the beds having high moisture content pose a health threat by transmitting pathogens between birds via litter (Oakley *et al.*, 2013).

Microbiota modulation by gut health additives

Various feed additives, viz. organic acids, essential oils, probiotics, prebiotics, exogenous

enzymes and trace minerals can support gut health, immunity and also modulate gut microbiota.

Organic acids: Organic acids are useful in the gut health and production performance of birds. These acids increase the *Lactobacillus* count in ileum and caecum of birds (Saki *et al.*, 2012). The organic acids lower chyme pH enhancing pepsin activity, whereas, the peptides obtained from pepsin proteolysis stimulate the release of hormones, viz. gastrin and cholecystokinin. These hormones trigger growth increasing protein digestion (Gauthier, 2002). Dietary supplementation of organic acids disturbs the integrity of bacterial cell membrane and cell macromolecules, thereby interfering nutrient transport and energy metabolism. It causes death of the bacteria in the gut (Ricke, 2003). Addition of organic acids in feed and in water to affect positively on the prevention of enteric diseases and enhanced the immunity, nutrient digestibility and overall production performances of poultry. Water hardness and alkaline water pH affect crop pH and consequently reduce the first phase of digestion (Kierończyk *et al.*, 2016). The crop possesses an important role in phytase and other enzyme activity. The enzyme activity is reduced in the tune of 10-15% when the pH value of the crop remains above 6.5. The effectiveness is high at pH 4.5-5.5 (Kierończyk *et al.*, 2016). The acidic condition within the crop of broilers is produced by organic acids in feed or water.

Essential oils: The phytogetic feed additives (PFAs) have got varying effects based on their composition. PFAs may act as bacteriostatic or immune-stimulating agents. One category of PFA is a mixture of essential oil compounds (EOC) (Hashemi and Davoodi, 2010). These EOCs viz. carvacrol, thymol and cinnam aldehyde possess selective antimicrobial properties (Lee *et al.*, 2002; Guo *et al.*, 2004). The proliferation of *C. perfringens* can be

reduced and control of coccidia infection can be made by the use of specific EOC blends (Guo *et al.*, 2004; Mitsch *et al.*, 2004; Oviedo-Rondón *et al.*, 2005, 2010). PFAs have the characteristics in maintaining the intestinal barrier function. It may be seen by increasing in the trans-epithelial electrical resistance of duodenal mucosa of broilers by including thymol in the diet (Placha *et al.*, 2014).

Exogenous enzymes: Being biologically active proteins the exogenous enzymes help in the breakdown of nutrients to smaller compounds hastening further digestion and absorption (Thacker, 2013). Exogenous enzymes including protease, lipase, phytase, and NSPase have been supplemented in diets to improve the digestibility of feed ingredients and modulate the gut microbiota of poultry (Adeola and Cowieson, 2011). Enzymes are the second-best tool to control the gut microbiota equilibrium. Protease, phytase and NSPase are popular feed supplements for their low-cost and productivity enhancer characteristics (Choct, 2009; Kiarie *et al.*, 2013). Inclusion of exogenous enzymes in diet reduces microbial proliferation by reducing the undigestible nutrients, phytate, digesta viscosity and irritation of gut mucosa that causes inflammation (Kiarie *et al.*, 2013).

Trace minerals: For better intestinal health, the present practice of supplementation of trace mineral to the poultry at higher dose is not advisable (Pierce *et al.*, 2009; Ao T and Pierce, 2013). Chelated form of organic trace mineral possesses different routes of absorption leading to lower interaction with other dietary components. Hence their bioavailability is more in compared to inorganic minerals (Mellor, 1964). The immunity development trace minerals are Zn, Mn, Cu, and Se. For modulation of the endogenous mechanisms of defense against infections, inflammations and oxidative stress, trace minerals viz. Zn and Cu

play crucial role (Mwangi *et al.*, 2017). Zinc is a micro-mineral with important function during the recovery of damage caused by enteric infections (MacDonald, 2000). The poultry industry has used prophylactic concentrations of dietary copper for its ability to improve feed conversion and antimicrobial activity (Bortoluzzi *et al.*, 2020). Manganese being a trace mineral related to better immunity support immunity (Kidd, 2004). Dietary selenium interacts with vitamin E in antioxidant protection of cells because it's a component of glutathione peroxidase (Kurutas, 2016).

Probiotics: Probiotics may cause modulation of gut micro flora and pathogen inhibition in poultry (Yegani and Krover, 2008; Mondal, 2018). Supplementation of probiotic in poultry diet enhanced nutrient digestibility and improved ileal and caecal microflora composition in the gut (Mountzouris *et al.*, 2010). Probiotics act by multiple mechanisms of action, viz. competitive exclusion of pathogenic bacteria, improved immune response, improve gut barrier function, production of bacteriocins, and improve microbiota homeostasis (Gaggia *et al.*, 2010; Mondal, 2018).

Prebiotics: Prebiotics are popularly known as non-digestible feed ingredients. They are used to manipulate the composition and metabolism of gut microbiota selectively (Piniero *et al.*, 2008). Prebiotics enhances the growth of Bifidobacteria and other species thereby improving the gut health (Scott *et al.*, 2020). These can be a potential feed additive to modulate microbiota for better growth and improved poultry health.

Microbiota composition vs. productive performance

Albeit the feed conversion ratio (FCR), calculated as the ratio of feed consumed to weight gained, is the most frequently used parameter; different other

traits, viz. residual feed intake (RFI), body weight gain (BWG), apparent metabolized energy (AME), time to achieve market weight are also used to assess the growth performance (Stanley *et al.*, 2013). The factors that influence the microbiota composition modulate the productivity and variability in performance in birds.

It has been observed that some bacteria are directly connected to productive performance of poultry. They are *Lactobacillus salivarius*, *Lactobacillus aviarius*, *Lactobacillus crispatus*, *Clostridium lactatifermentans*, besides members of family *Ruminococcaceae*, *Bacteroides vulgatus*, *Akkermansia* and *Faecalibacterium* (Yan *et al.*, 2017). The high prevalence of coliforms in gut leads to lower fat digestibility and consequently lower growth of broiler. On the other hand, colonization of *Campylobacter* in the gut of broiler was observed to enhance cumulative FCR leading to economic loss 2015; (Awad *et al.*, 2015; Rubio *et al.*, 2015).

The restrictive feeding strategy was considered to be an option to reveal the effect of feed intake upon microbial colonization in ileum and cecum vis-à-vis physiological activities of poultry. It was done with different residual feed intake (RFI) as measure of feed efficiency. It was observed that the predominant families, viz. *Turicibacteraceae*, *Ruminococcaceae*, and *Enterobacteriaceae* were affected by restrictive feeding more in both sections of gut regardless of RFI (Siegerstetter *et al.*, 2018). Further, few taxa were found to be connective with productivity level compared with the impact of nutrient availability on the microbiota richness.

It was observed that *Acinetobacter*, *Anaerosporebacter*, and *Arcobacter* were abundant in faecal matter in birds having the lower feed efficiency group whereas members of *Enterobacteriaceae* and *Faecalibacterium* were found to be prevalent in the better feed efficiency group. However, the relative

abundance of some bacteria in feces should not be corroborated with the prevalence of similar microbiota in poultry GIT (Yan *et al.*, 2017; Siegerstetter *et al.*, 2018). Therefore, one should be cautious in interpreting results while comparing or evaluating productive performance of poultry birds (Diaz Carrasco *et al.*, 2019).

In short, the association of gut microbiota and productivity of poultry has been studied widely and found to be quite close. However, the findings are not always anticipated. Most of the time, identification of specific bacteria related to the productive performances and establishing cause/effect relationship is difficult.

Conclusion

Gut microbiota is an important component of gastrointestinal ecosystem. Modulation of composition and function of the gut microbiota by improving feed and water quality, environmental conditions, farm management, biosecurity, hatchery conditions, breeder health and nutrition and use of various gut health additives like organic and essential oils, trace minerals, probiotics and prebiotics can play vital role for successful poultry production. Modulations of gut microbiota by implementing dietary and managerial strategies have been used by poultry producers to enhance bird's performance and reduce the incidence of diseases. Nonetheless gut microbiota and productive performance of poultry has got close relationship, more studies are needed to identify specific gut microbial population that can be exploited to enhance productivity.

Conflict of interest: Authors declare that they have no conflict of interest.

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