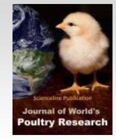
JWPR
Journal of World's Poultry Research

2019, Scienceline Publication

J. World Poult. Res. 9(4): 217-223, December 25, 2019

Review Paper, PII: S2322455X1900028-9



DOI: https://dx.doi.org/10.36380/jwpr.2019.27

Probiotics and Poultry Gut Microflora

Kibrnesh Tegenaw Tsega[1, 3]*, John Kagira Maina[2] and Nega Berhane Tesema[3]

[1]*Department of Molecular Biology and Biotechnology, Pan-African University Institute for Basic Sciences, Technology and Innovation, Nairobi, Kenya*
[2]*Department of Animal Sciences, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya*
[3]*Institute of Biotechnology, University of Gondar, Gondar, Ethiopia*
*****Corresponding author's E-mail: kibiramare372@gmail.com; ORCID: 0000-0003-1630-4212

Received: 28 Oct. 2019
Accepted: 09 Dec. 2019

ABSTRACT

Poultry production is presently the most effective animal production industry and provides an excellent source of protein production worldwide. The poultry gastrointestinal microbiota includes commensal, mutualistic and pathogenic microbes. The relationship between host and gut microbiota can affect the balance of mutualism and pathogenicity. The imbalanced gut microflora caused by the incidence of disease, hygiene conditions, diet, management practices, and environmental stress affects the survival and productivity of chicken. Maintenance of the gut microbial composition is possible through the regulation of the gastrointestinal microbiota by suppressing the growth of pathogens. For many years, antibiotic growth promoters have been used to manage these problems. Nowadays, because of the emergence of antibiotic-resistant bacteria, other alternatives are being sought. Supplementation of probiotics as feed additives is considered to enhance chicken productivitity and to protect the gut from pathogen colonization and help to tolerate environmental stress. The goal of the present article was to review the poultry gastrointestinal microflora and probiotics role in the health and growth of poultry. In addition, this article focused on probiotic microorganisms and their potential characteristics.

Key words: Gastrointestinal microbiota, Poultry, Probiotics

INTRODUCTION

Poultry production is currently the most efficient animal production system and forms the basis of global protein production (USDA, 2019). The advantage of poultry production depends on the ability of chickens to efficiently convert feed into muscle mass. This makes them an effective system for producing high-quality proteins (Phillippa et al., 2018). According to FAO (2012), poultry refers to the domestic birds including domestic chickens (*Gallus gallus* domesticus), turkeys, ducks, geese, dove, and other domesticated birds that are raised to produce eggs and meat. Among these, chicken production is the most popular worldwide. The interaction between the biochemical functions of the poultry and the intestinal microbiota is involved in extracting energy and nutrients from food. Thus, the selection of beneficial microbiota plays an important role in improving production performance, detoxification, modulation of the immune system and protection against pathogens (Clavijo and Florez, 2018). In the poultry, different organs contribute to the digestion and absorption process of nutrients. Microorganisms present in each organ of the digestive system have independent functions and different taxonomic composition. As a result, gut organs are considered as separate ecosystems for microbes despite the deep interconnection between gut microflora (Wielen et al., 2002).

The microbiota in the poultry gastrointestinal (GI) tract includes commensal, mutualistic and pathogenic microorganisms. The gut microbiota positively influences the GI development, immunological and physiological functions of the gut. In poultry, these microorganisms colonize the GI tract during the early post-hatch period and form a synergistic relationship with the host (Torok et al., 2008). Chicken gut microflora composition changes in relation to the age of chickens, dietary factors, breed, and geographic location. The different factors related to diet, infectious agents, environmental and management conditions negatively affect the balance of poultry gut microbiota, which consequently impairs feed conversion ratio and growth performance (Yegani and Korver, 2008). The balance between pathogenicity and mutualism can be determined by the relationship between the host and its gut microbiota. Modulation of the GI microbiota by suppressing the growth of pathogens helps to maintain the optimal microbial composition. Hence, the inclusion of antibiotic growth promoters in animal diets improves growth and feed conversion efficiency (Dumonceaux et al. 2006). The emergence of antibiotic-resistant bacteria causes the growing global concerns related to the transmission of these bacteria from animals to humans. This global concern has led to limiting the usage of antibiotics in livestock (Apata, 2012). Therefore, the alternative attention is concentrated on the use of probiotic microorganisms and other products such as enzymes, organic acids, bacteriocins, bacteriophages and nanoparticles that can similarly enhance poultry productivity and produce safe edible products (Mehdi et al. 2018). In addition, following the European Union ban on the use of prophylactic antibiotics in poultry nutrition, scientists currently enforced to seek alternatives to antibiotic growth promoters to produce safe and efficient poultry meat and egg (Saeed et al. 2017).

Microflora in the chicken gastrointestinal tract

The digestive tract of chickens is comprised of the crop, proventriculus, gizzard small and large intestines and ceca (Nasrin et al., 2012). In addition, gut microflora, gut-associated immune tissue, liver, gall bladder, and pancreas are other important components of the digestive system (Dibner and Richards, 2004). The bacteria are the most abundant microbes of the GI tract. Approximately, there are up to 10^{10}-10^{11} bacteria per gram of cecal content. Fungi and protozoa are the other gut inhabitant microbes (Albazaz and Buyukunal, 2014). Archaea which is represented predominantly by methanogenic *Methanobrevibacter* are other microorganisms colonized in chicken gut (Saengkerdsub et al. 2007). The specialized microbial communities in the GI tract perform important digestive functions as feed passes (Oakley et al. 2014). In chicken, the main bacterial activities are found in crop, small intestine, and cecum (Albazaz and Buyukunal, 2014). According to the report of (Youssef et al., 2017) inclusion of probiotics on poultry feed resulted in a numerical reduction in intestinal aerobes and fecal coliforms. Furthermore, all probiotics used significantly reduced total aerobic and staphylococci counts in the carcass meat, with a numerical decline in *E. coli* count. A prolonged feed retention time in the crop is associated with significant degradation of starch and fermentation of lactate mediated by the microbial community with the predominance of various *Lactobacillus* species. Also, *Clostridiaceae* family resides in the crop (Svihus, 2014). The species of *Lactobacillus* and *Clostridiaceae* also are present in the gizzard. However, the existence of pepsin, gastric juices and hydrochloric acid in the gizzard decreases the pH and leads to reduced bacterial populations and fermentation activity (Clavijo and Florez, 2018). In poultry, the lower intestinal tract involves the small intestine, the colon, and two big cecal chambers which are important for the fermentation process (Sekelja et al., 2012). The small intestine is colonized mainly by *Lactobacilli* followed by *Streptococci* and *Enterobacteria*. On the other hand, the caecum is colonized mainly by strict anaerobes and a small number of facultative anaerobes (Cisek and Binek, 2014). The alimentary tract in newly hatched healthy chicken is usually sterile. The development of chicken intestinal microflora depends on their contact with bacteria from the environment within the first days after hatching. Differences in bacteria ingestion from hatching debris, environment, producing facility, feed and water cause variation in the microbial populations (Binek et al., 2000). On the first day of chick's life, the cecal microflora consists mainly of *Enterobacteriaceae*, *Enterococcus* and *Lactobacillus* species. After the second week of age, *Bacteroides* and *Eubacterium* species were established (Borda-Molina et al., 2018). Various species, different individuals of the same species and distinct sections of the GI tract have a different composition of microorganisms. In addition, the gut microflora is unstable over time (Dibner and Richards, 2004).

Impact of poultry gut microorganism on host

The gut is a natural barrier between the host and the intestinal microflora. There are numerous bacterial cell communities and millions of genes in the host. The expression of this amount of genes helps them to perform numerous enzymatic reactions that the host is not able to catalyze. This enables the microflora to influence many aspects of intestinal tract development and to provide metabolic contributions to the host (Yeoman et al., 2012). Generally, the gut microflora has a prominent role in digestion, metabolism, vitamin synthesis, immune stimulation and pathogen exclusion (Amit-Romach et al., 2004). Production of highly specialized hydrolytic enzymes by gut microorganisms allows degradation of complex substrates like non-starch polysaccharides and other indigestible carbohydrates (Sergeant et al., 2014). This hydrolysis allows further fermentation of the feed components by other members of the gut ecosystem that generate short-chain fatty acids, which in turn become accessible to the host as energy and carbon sources.

(Wang et al. 2016). The products and activities of hydrolytic enzymes create an ecosystem that is appropriate for some bacterial genera and hostile to others (Panda et al. 2009). Apart from nonpathogenic microbes, harmful members of the gut microflora may be involved in local or systemic infections, intestinal putrefaction and toxin formation (Yasothai, 2017). Enteric pathogens such as *Escherichia*, *Campylobacter*, *Vibrio*, *Shigella*, *Yersinia*, and *Salmonella* are a major cause of poultry morbidity and mortality throughout the world. Gram-negative enteric pathogens cause diarrhea and fever (Foley et al. 2013).

Probiotic microorganisms

The term probiotic has been defined as "a live microbial feed supplement which beneficially affects the host by improving its intestinal microbial balance" (Fuller, 1989). Probiotics stimulate the growth of beneficial microorganisms, reduce the number of pathogens, and lower the risk of gastrointestinal diseases (Getachew, 2016). These living microorganisms are nonpathogenic and harmless in nature, that are favorable to the host's health when properly administered through the digestive route (FAO/WHO, 2001). These microorganisms include different species that belong to bacteria, fungi, and yeasts (Chen and Zhu, 2017). Youssef et al. (2017) also reported that probiotics and acidifiers can be used as potential alternatives to antibiotics in broiler diets. Different microbial species or different strains of the same species have different probiotic potential. Specific receptor sites and particular immunological properties are some of the reasons accounting for this difference (Hadisaputro and Harimurti, 2015). Probiotic microorganisms can be isolated from plants, food products, environment, human and animal sources (Hossain et al., 2012). Different studies reported the isolation of potential probiotic strains from the natural poultry gut microflora (Ehrmann et al. 2002, Shin et al. 2008). Competitive elimination of pathogenic microbes, production of antibacterial products (such as bacteriocins and colicins) and immune modulation are the basic mechanisms of probiotics. Live non-pathogenic microbial strains, either single or multi-strain, belonging to the genera *Lactobacillus*, *Streptococcus*, *Bacillus*, *Enterococcus*, *Pediococcus*, *Aspergillus*, and *Saccharo-myces* are used in poultry (Dhama et al. 2011).

Role of probiotics in poultry production

The poultry industry is a significant financial activity across the globe. Heavy financial losses occur when birds are subjected to stressful environmental conditions and disease. The emergence of a wide range of antibiotic-resistant bacteria and pathogens are the main limiting factors for the poultry industry productivity (Kabir, 2009). A stable protective flora is established naturally in the poultry gut. Some dietary and environmental factors such as stress, antibiotic treatment, and excessive hygiene influence the stable protective gut microflora (Donaldson et al. 2017). Probiotic supplements are used to reconstitute the natural flora of chicken. Different strains of bacteria capable of surviving and inhabiting in the gut are used as probiotics. However, probiotics can be harmful to immunocompromised populations. The correct dosage of probiotic administration has not yet been established (Getachew, 2016). Several studies have been described the role of different probiotic *Lactobacillus* strains in chicken productivity and health. A study which involved the use of feed supplemented with *Lactobacillus* culture (1 g *Lactobacillus* culture /1 kg feed) in pure Hubbard and pure Shaver chicks from day 21 to 42 resulted in greater weight gain and heat tolerance in comparison to controls (Zulkifli et al. 2010). *Escherichia coli*, different species of *Salmonella enterica* and *Campylobacter jejuni* are the primary pathogens of poultry farming. The administration of *Lactobacillus* probiotics decreases enteric pathogenic microbes through competitive exclusion in the poultry intestinal tract and improves the intestinal well-being (Hadisaputro and Harimurti, 2015). According to Bansal et al. (2011), broiler chicks fed a diet with probiotic yeast gained significantly higher weight than control groups. In addition, dietary intake of Kefir as a probiotics source resulted in a decrease in chicken liver weight (Vahdatpour and Babazadeh, 2016). Diet supplemented to Protexin® probiotic alone or in combination with Fermacto® prebiotic increased growth hormone level and improved growth performance in quails (Nikpiran, 2014). The administration of probiotic supplements via drinking water significantly improved the weight gain in Kenyan indigenous chicken (Atela et al., 2015). The positive effects on weight gain and feed conversion ratio were observed in quails that received synbiotics (Babazadeh et al. 2011). The addition of probiotics to feed increase feed efficiency, growth performance, egg production, meat and egg quality as well as cholesterol level in poultry products (Getachew, 2016; Popova, 2017).

Role of probiotics in protecting poultry gastrointestinal infection

The probiotic microbes have the capacity to inhibit the development of pathogenic microorganisms in the gut of poultry (Getachew, 2016). Supplementation of probiotic products allows manipulation of the GI microbiota. For example, *Listeria monocytogenes* is one of the pathogenic microbes that affect the poultry GI tract. Administration of multi-strain probiotic containing different *Lactobacillus* species and *Bacillus amyloliquefaciens* prevents the establishment and spread of this bacterium in the GI tract of broiler chickens (Neveling et al. 2017). In another study, the administration of commercial probiotic preparation formulated from different species of *Lactobacillus* and *S. cerevisiae* reduced the stress of *E.coli* K88 infected Hubbard broiler chicks and reduces *E.coli* proliferation in GI tract (Mohamed and Younis, 2018). According to Forkus et al. (2017), the production of the antimicrobial peptide known as Microcin J25 by engineered *E.coli* inhibits colonization of *Salmonella enterica* in the turkey GI tract. *Clostridium perfringens* is a pathogenic microbe that causes necrotic enteritis in poultry and negatively affects poultry health and productivity. Inclusion of *Lactobacillus johnsonii* BS15 to the feed reduces the incidence of necrotic enteritis and damage of villi by necrotic enteritis in Cobb 500 chicks (Wang et al. 2017). Administration of *Lactobacillus plantarum* K KKP 593/p and *Lactobacillus rhamnosus* KKP 825 via feed or drinking water reduce the number of *E.coli* in ROSS 308 broiler chickens (Michalczuk, 2019). According to Shokryazdan et al. (2017), supplementation of chicken feed with a mixture of *L. salivarius* strains improved populations of lactobacilli and decreased harmful bacteria including *E.coli* and total aerobes. Intestinal microbial modification through early probiotic inoculation has a role in improving the weight gain of the host.

At-hatch administration of beneficial strains has different results compared to the natural acquisition of the same strain from the environment (Baldwin et al. 2018). At-hatch administration as compared to natural acquisition improved feed conversion rate, growth performance, resistance to disease, digestion and absorption of nutrients, and carcass quality (Mohan, 2015). Synthesis of the antimicrobial compounds by the probiotic species, such as *Lactobacillus* spp., *Pediococcus acidilactici*, *Lactococcus lactis,* and *Enterococcus faecium* is one mechanism to prevent pathogens colonization. These antimicrobial products including short-chain fatty acids, bacteriocins, hydrogen peroxide, etc. inhibit or kill bacteria such as *Staphylococcus aureus*, *E. coli*, *Clostridium perfringens*, *Salmonella typhimurium*, *Bacillus* spp., *Listeria* spp., *Klebsiella* spp. and *Proteus* spp. by binding to the specific receptors and causing cell damage (Cisek and Binek, 2014).

Characterization of probiotic microbes

The characterization of probiotic is based on the consensus of scientists on some criteria, with particular attention being paid to the ecological origin of the bacteria, tolerance level to the harsh stomach and small intestine environments and capacity to bind to intestinal surfaces (Koenen et al. 2004). In general, microorganisms with potential probiotic advantages share common characteristics. The common requirements or properties of probiotics are discussed below.

General properties of probiotics

During the isolation process of microorganisms for probiotics, different selection criteria should be used as a reference. According to Kosin and Rakshit (2006) and Fuller (1989) some of the conventional criteria that can be applied for the selection of microbial species as probiotics comprise biosafety, the origin of the strain, resistance to GI tract conditions, intestinal adhesion and colonization, antimicrobial activity, stimulation of immune response, survival and stability throughout processing and storing (Khalil et al. 2018). In order to produce the desired effect, the probiotics strains should have a property to grow and survive in the digestive system of the host as they are exposed to a range of stressful conditions in the gut including lower pH, bile and pancreatic juice (Jose et al. 2015). The effects of simulated gastric juice and bile acids on the growth of probiotics are varied among species and strains. Species or strains with the greatest tolerance to acid and bile are excellent targets for the development of probiotics products. In addition, isolates with high tolerance to heat can be selected to produce probiotics (Hossain et al. 2012). Adhesion of the probiotics microbes to the intestinal mucosa is regarded as a precondition for colonization in the GI tract. This capacity to adhere is one of the most significant requirements for the choice of probiotics (Harzallah and Belhadj, 2013). The selection of probiotics also focuses on the safety of microorganisms. Hence, probiotics should be non-pathogenic and have no adverse effect on the host. The probiotic itself or its fermentation products or cell components should not be pathogenic, allergic, mutagenic, and carcinogenic (Harzallah and Belhadj, 2013). As an advantage, the probiotic strains should act as an adjuvant and stimulate the immune system against pathogenic microorganisms (Jose et al. 2015).

One of the safety considerations for selecting a potential probiotic strain is that it does not contain antibiotic resistance genes that can be transferred to the pathogenic microorganisms (Shakoor et al. 2017).

Probiotics microbes may be subjected to antibiotics in the animal gut when antibiotics are used as medicinal products for animal health. As a result, to be effective, the probiotics strains should possess non-transferable resistance which aids them *in vivo* survival (Shakoor et al. 2017). The resistance of probiotics isolates to some antibiotics is considered as an intrinsic property, presenting no safety concerns in feed or food (Khalil et al. 2018). Antagonistic activity of probiotics microorganisms against pathogens is regarded as a characteristic of probiotic to maintain the gut microflora balanced and to keep the gut rid of pathogens. Probiotics inhibit the growth of pathogenic bacteria through the production of nonspecific antimicrobial compounds such as hydrogen peroxide, short-chain fatty acids, and low molecular weight proteins known as bacteriocins and bacteriocin-like inhibitory substances (Torshizi et al., 2008).

Technological characteristics of probiotics

For the wide-scale distribution of probiotics strains, they must be manufactured under industrial conditions. These probiotic microorganisms have to survive and retain their functionality during storage as frozen or freeze-dried cultures. Similarly, their incorporation into foods or feeds should not provide unpleasant flavors or textures (Saarela et al. 2000). Technological evaluations include pH, salt and bile acid tolerance, hydrogen peroxide production, utilization of different carbon sources, enzymatic activities, hemolytic properties, antibiotics sensitivity, antimicrobial activity and *in vitro* adherence properties (Abiodun et al. 2013). Large scale production of probiotics involves a fermentation process. During fermentation reactions, the probiotics strains may be exposed to different temperature conditions. In addition, the storage and transport process of probiotics products should be under the optimum temperature. Thermophilic organisms have the advantage of tolerating higher temperatures during processing and storage. They have a better chance of remaining viable during the drying process required for prolonged storage and thus become distinctly effective products (Kosin and Rakshit, 2006).

Importance of probiotic research

The animal production system has a considerable impact on the nutrition and health status of consumers. Animal intestinal pathogenic microbes including *Salmonella*, *Campylobacter*, *Yersinia,* and *Listeria* are the major cause of food contamination and zoonosis. Different methods of animal production are introduced to increase productivity, quality, and safety of animal products, besides protecting animal welfare and the natural environment (Markowiak and Slizewska, 2018). Previously, different medicinal products and antibiotics had been widely utilized to modify the animal gut microflora to enhance productivity and improve animal growth. However, the emergence of drug-resistant microorganisms has been occurred due to the long-term use of antibiotics and other medicinal products which causes a great fear to consumers and it also exerts negative impacts on the environment (Apata, 2012). The usage of probiotics is mentioned as one of the alternatives (Mehdi et al., 2018). Investigation of locally produced probiotics, targeting animals based on their surrounding environment and feed is important to maximize probiotics efficacy and to create market opportunities. Particularly, people in developing countries who do not have access to probiotics and live in different geographical locations will be benefited from locally sourced probiotics (Sybesma et al. 2015).

CONCLUSION

In general, the present review revealed that an effective dose of probiotics can have a dominant role in the improvement of intestinal microflora and production performance. In addition, it can inhibit the development of pathogenic microorganisms in the gut.

DECLARATION

Competing interests

The authors have no competing interests.

Authors' contribution

Kibirnesh Tegenaw designed the review, collected the information, and wrote the manuscript. Dr. Kagira and Prof. Nega collected the information and revised the manuscript.

REFERENCES

Abiodun S, Charles F, Ulrich S, Melanie H, Claudia G and Wilhelm H (2013). Characterization and technological properties of lactic acid bacteria in the production of sorghurt a cereal-based product. Food Biotechnology, 27(2): 178–198. DOI: https://doi.org/10.1080/08905436.2013.781949

Albazaz RI and Buyukunal BE (2014). Microflora of digestive tract in poultry. KSU Journal of Natural Sciences, 17(1): 39–42. DOI: http://dx.doi.org/10.18016/ksujns.40137

Amit-Romach E, Sklan D and Uni Z (2004). Microflora ecology of the chicken intestine using 16S ribosomal DNA primers. Poultry Science, 83(7): 1093–1098. DOI: https://doi.org/10.1093/ps/83.7.1093

Apata DF (2012). The emergence of antibiotics resistance and utilization of probiotics for poultry production. Science Journal of Microbiology, (2): 8–13. Available at: https://www.sjpub.org/sjmb/abstract/apata-abstract.html

Atela A, Tuitoek J, Onjoro PA and Kibitok N (2015). Effects of probiotics feeding technology on weight gain of indigenous chicken in Kenya. IOSR Journal of Agriculture and Veterinary Science, 8(11): 33–36. DOI: https://doi.org/10.9790/2380-081123336

Babazadeh D, Vahdatpour T, Nikpiran H, Jafargholipour MA and Vahdatpour S (2011). Effects of probiotic, prebiotic and synbiotic intake on blood enzymes and performance of Japanese quails (Coturnix Japonica). Indian Journal of Animal Sciences, 81(8): 106–110. Available at: http://vahdatpour.iaushab.ac.ir/uploads/2011-7.pdf

Baldwin S, Hughes RJ, Van TH, Moore RJ and Stanley D (2018). At-hatch administration of probiotic to chickens can introduce beneficial changes in gut microbiota. PLoS One, 13(3): 1–14. DOI: https://doi.org/10.1371/journal.pone.0194825

Binek M, Borzemska W, Pisarski R, Kosowska G, Malec H and Karpin´ska E (2000). Evaluation of the efficacy of feed providing on development of gastrointestinal microflora of newly hatched broiler chickens. Archiv Für Geflügelkunde, 64(4): 147–151. Available at: https://www.european-poultry-science.com/artikel.dll/2000-64-147-151_ndk3mdk2mq.pdf

Borda-Molina D, Seifert J and Camarinha-Silva A (2018). Current perspectives of the chicken gastrointestinal tract and its microbiome. computational and structural Biotechnology Journal 16: 131–139. DOI: https://doi.org/10.1016/j.csbj.2018.03.002

Chen F, Zhu L and Qiu H (2017). Isolation and probiotic potential of *Lactobacillus salivarius* and *Pediococcus pentosaceu*s in specific pathogen free chickens. Brazilian Journal of Poultry Science, 19(2): 325–332. DOI: http://dx.doi.org/10.1590/1806-9061-2016-0413

Cisek A and Binek M (2014). Chicken intestinal microbiota function with a special emphasis on the role of probiotic bacteria. Polish Journal of Veterinary Sciences, 17(2): 385–394. Available at: https://www.ncbi.nlm.nih.gov/pubmed/24988871

Clavijo V and Flórez MV (2018). The gastrointestinal microbiome and its association with the control of pathogens in broiler chicken production: A review. Poultry Science, 97(3), 1006–1021. DOI: https://doi.org/10.3382/ps/pex359

Dhama K, Verma V, Sawant PM, Tiwari R, Vaid RK and Chauhan RS (2011). Applications of probiotics in poultry: Enhancing immunity and beneficial effects on production performances and health. Journal of Immunology and Immunopathology, 13(1): 1-19. Available at: http://indianjournals.com/ijor.aspx?target=ijor:jii&volume=13&issue=1&article=001

Dibner JJ and Richards JD (2004). The digestive system: challenges and opportunities. Journal of Applied Poultry Research, 13(1): 86–93. DOI: https://doi.org/10.1093/japr/13.1.86

Donaldson EE, Stanley D, Hughes RJ, and Moore RJ (2017). The time-course of broiler intestinal microbiota development after administration of cecal contents to incubating eggs. Peer J, 5: e3587. DOI: https://doi.org/10.7717/peerj.3587

Dumonceaux TJ, Hill JE, Hemmingsen SM and Kessel AG (2006). Characterization of intestinal microbiota and response to dietary virginiamycin supplementation in the broiler chicken. Applied and Environmental Microbiology, 72(4): 2815–2823. DOI: https://doi.org/10.1128/AEM.72.4.2815

Ehrmann MA, Kurzak P, Bauer J, and Vogel RF (2002). Characterization of lactobacilli towards their use as probiotic adjuncts in poultry. Journal of Applied Microbiology, 92(5): 966–975. DOI: https://doi.org/10.1046/j.1365-2672.2002.01608.x

FAO/WHO (2001). Health and nutritional properties of probiotics in food including powder milk with live lactic acid bacteria; Report of a Joint FAO/WHO Expert consultation on evaluation of health and nutritional properties of probiotics in food including powder. pp. 1–34. DOI:https://doi.org/10.1201/9781420009613.ch16

Foley SL, Johnson TJ, Ricke SC, Nayak R and Danzeisen J (2013). Salmonella pathogenicity and host adaptation in chicken-associated. Journal of microbiology and molecular biology reviews, 77(4): 582–607. DOI: https://doi.org/10.1128/MMBR.00015-13

Forkus B, Ritter S, Vlysidis M, Geldart K and Kaznessis YN (2017). Antimicrobial probiotics reduce *Salmonella enterica* in turkey gastrointestinal tracts. Scientific Reports, 17: 1–9. DOI:https://doi.org/10.1038/srep40695

Fuller R (1989). Probiotics in man and animals. Journal of Applied Bacteriology, 66: 365–378. DOI:https://doi.org/10.1111/j.1365-2672.1989.tb05105.x

Getachew T (2016). A Review on effects of probiotic supplementation in poultry performance and cholesterol levels of egg and meat. Journal of World Poultry Research, 6 (61): 31–36. Available at: http://jwpr.science-line.com/attachments/article/35/J%20World%20Poult%20Res%206(1)%2031-36,%20March%202016.pdf

Hadisaputro W, and Harimurti S (2015). Probiotics in poultry. Journal of microbiology monographs, 29: 1–21. DOI: https://doi.org/10.1007/978-3-319-23183-9

Harzallah D and Belhadj H (2013). Lactic acid bacteria as probiotics : characteristics, selection criteria and role in immunomodulation of human GI muccosal barrier, lactic acid bacteria- R&D for Food, Health and Livestock Purposes, Marcelino Kongo, IntechOpen. DOI:https://doi.org/http://dx.doi.org/10.5772/50732

Hossain ME, Ko SY, Kim GM., Firman, JD and Yang CJ (2012). Evaluation of probiotic strains for development of fermented *Alisma canaliculatum* and their effects on broiler chickens. Poultry Science, 91(12): 3121–3131. DOI:https://doi.org/10.3382/ps.2012-02333

Jose N, Bunt C and Hussain M (2015). Comparison of microbiological and probiotic characteristics of lactobacilli isolates from dairy food products and animal rumen contents. Microorganisms Open Access Journal, 3(2): 198–212. DOI: https://doi.org/10.3390/microorganisms3020198

Kabir SL (2009). The role of probiotics in the poultry industry. International Journal of Molecular Sciences, 10(8): 3531–3546. DOI: https://doi.org/10.3390/ijms10083531

Khalil ES, Manap MY, Mustafa S, Amid M, Alhelli AM and Aljoubori A (2018). Probiotic characteristics of exopolysaccharides-producing lactobacillus isolated from some traditional Malaysian fermented foods. CYTA - Journal of Food, 16(1): 287–298. DOI:https://doi.org/10.1080/19476337.2017.1401007

Koenen M, van der Hulst R, Leering M, Jeurissen S and Boersma W (2004). Development and validation of a new in vitro assay for selection of probiotic bacteria that express immune-stimulating properties in chickens in vivo. FEMS Immunology and Medical Microbiology, 40(2): 119–127. DOI:https://doi.org/10.1016/S0928-8244(03)00306-7

Kosin B and Rakshit SK (2006). Microbial and processing criteria for production of probiotics: A review. Food Technology and Biotechnology, 44(3): 371–379. Available at: https://hrcak.srce.hr/109917

Markowiak P and Śliżewska K (2018). The role of probiotics , prebiotics and synbiotics in animal nutrition. Gut Pathogens, 10(21): 1–20. DOI: https://doi.org/10.1186/s13099-018-0250-0

Mehdi Y, Létourneau-montminy MP, Gaucher ML, Chorfi Y, Gayatri S, Rouissi T and Godbout S (2018). Use of antibiotics in broiler production: Global impacts and alternatives. Animal Nutrition Journal, 4(2): 170–178. DOI: https://doi.org/10.1016/j.aninu.2018.03.002

Michalczuk M (2019). Comparison of the effect of lactic acid bacteria added to feed or water on growth performance , health status and gut microbiota of chickens broilers or water on growth performance, health status and gut microbiota. Annals of Warsaw University of Life Sciences, 58(1): 55–56.

DOI:https://doi.org/10.22630/AAS.2019.58.1.7

Mohamed HA and Younis W (2018). Trials on the role of prebiotics and probiotics in colonization and immune response of broiler chickens challenged with *Escherichia coli* K88. Alexandria Journal of Veterinary Sciences, 58(1): 48–56. DOI:https://doi.org/10.5455/ajvs.297887

Mohan V (2015). The role of probiotics in the inhibition of *Campylobacter jejuni* colonization and virulence attenuation. European Journal of Clinical Microbiology and Infectious Diseases, 34(8): 1503–1513. DOI: https://doi.org/10.1007/s10096-015-2392-z

Nasrin M, Siddiqi MNH, Masum MA and Wares MA (2012). Gross and histological studies of digestive tract of broilers during postnatal growth and development. Journal of Bangladesh Agricultural University, 10(1): 69–77. DOI:https://doi.org/10.3329/jbau.v10i1.12096

Neveling DP, Emmenes L, Van Ahire JJ, Pieterse E, Smith C and Dicks LMT (2017). Safety assessment of antibiotic and probiotic feed additives for *Gallus gallu*s domesticus. Scientific Reports. Journal of Feed Science and Technology, 7: 1–17. DOI:https://doi.org/10.1038/s41598-017-12866-7

Nikpiran H, Vahdatpour T, Babazadeh D, Tabatabaei SM and Vahdatpour S (2014). Effects of functional feed additives on growth influenced hormones and performance of Japanese quails (*Coturnix japonica*). Greener Journal of Biological Sciences, 4: 39-44. DOI: https://doi.org/10.15580/GJBS.2014.2.021014096

Oakley BB, Lillehoj HS, Kogut MH, Kim WK, Maurer JJ, Pedroso A and Cox NA (2014). The chicken gastrointestinal microbiome. FEMS Microbiology Letters, 360(2): 100–112. DOI: https://doi.org/10.1111/1574-6968.12608

Panda AK, Rao SVR, Raju MVL and Sunder GS (2009). Effect of butyric acid on performance, gastrointestinal tract health and carcass characteristics in broiler chickens. Asian-Australasian Journal of Animal Sciences, 22(7): 1026–1031. DOI: https://doi.org/10.5713/ajas.2009.80298

Connerton PL, Richards PJ, Lafontaine GM, O'Kane PM, Ghaffar N, Cummings NJ, Smith DL, Fish NM and Connerton IF (2018). The effect of the timing of exposure to *Campylobacter jejuni* on the gut microbiome and inflammatory responses of broiler chicken*s.* Microbiome, 6(1), 88. DOI: https://doi.org/10.1186/s40168-018-0477-5

Popova T (2017). Effect of probiotics in poultry for improving meat quality. Current Opinion in Food Science, 14, 72–77. DOI: https://doi.org/10.1016/j.cofs.2017.01.008

Saarela M, Mogensen G, Fondén R, Mättö J and Mattila-Sandholm T (2000). Probiotic bacteria: safety, functional and technological properties. Journal of Biotechnology, 84(3), 197–215. DOI:https://doi.org/10.1016/S0168-1656(00)00375-8

Saeed M, Ahmad F, Asif Arain M, Abd El-Hack ME and ABZ (2017). Use of mannan- oligosaccharides (mos) as a feed additive in poultry nutrition. Journal of World's Poultry Research, 7(3): 94–103. Available at: http://jwpr.science-line.com/attachments/article/42/J%20World%20Poult%20Res%207(3)%2094-103,%202017.pdf

Saengkerdsub S, Herrera P, Woodward C, Anderson R, Nisbet D and Ricke S (2007). Detection of methane and quantification of methanogenicarchaea in faeces from young broiler chickens using real-time PCR. Letters in Applied Microbiology, 45(6): 629–634. DOI: https://doi.org/10.1111/j.1472-765X.2007.02243.x

Sekelja M, Rud I, Knutsen SH, Denstadli V, Westereng B, Næs T and Rudi K (2012). Abrupt temporal fluctuations in the chicken fecal microbiota are explained by its gastrointestinal origin. Applied and Environmental Microbiology, 78(8): 2941–2948. DOI:https://doi.org/10.1128/AEM.05391-11

Sergeant MJ, Constantinidou C, Cogan TA, Bedford MR, Penn CW and Pallen MJ (2014). Extensive microbial and functional diversity within the chicken cecal microbiome. PLoS ONE, 9(3). DOI:https://doi.org/10.1371/journal.pone.0091941

Shakoor G, Akbar A, Samad A, Khan SA, Ur F, Shakoor M and Ahmad D (2017). Isolation of lactic acid bacteria from chicken gut and its probiotic potential characterization. International Journal of Biosciences, 11(3): 1–9. DOI: http://dx.doi.org/10.12692/ijb/11.3.1-9

Shokryazdan P, Faseleh M and Liang JB (2017). Effects of a *Lactobacillus salivarius* mixture on performance, intestinal health and serum lipids of broiler chickens. Plos One, 12(5): 55–68. DOI: https://doi.org/10.1371/journal.pone.0175959

Svihus B (2014). Function of the digestive system. Journal of Applied Poultry Research, 23(2): 306–314. DOI: https://doi.org/10.3382/japr.2014-00937

Sybesma W, Kort R and Lee Y (2015). Locally sourced probiotics, the next opportunity for developing countries Trends in Biotechnology, 33(4): 197–200. DOI:https://doi.org/10.1016/j.tibtech.2015.01.002

Torok VA, Ophel-Keller K, Loo M and Hughes RJ (2008). Application of methods for identifying broiler chicken gut bacterial species linked with increased energy metabolism. Applied and Environmental Microbiology, 74(3): 783–791. DOI:https://doi.org/10.1128/AEM.01384-07

Torshizi MAK, Rahimi S, Mojgani N, Esmaeilkhanian S and Grimes JL (2008). Screening of indigenous strains of lactic acid bacteria for development of a probiotic for poultry. *Asian*-Australasian Journal of Animal Sciences, 21(10): 1495–1500. DOI:https://doi.org/10.5713/ajas.2008.80081

USDA (2019). Livestock and poultry: world markets and trade. United States Department of Agriculture and Foreign Agricultural Service, p. 31. DOI:https://doi.org/10.1016/S1097-8690(11)70006-3

Vahdatpour T and Babazadeh D (2016). The effects of kefir rich in probiotic administration on serum enzymes and performance in male Japanese quails. Journal of Animal and Plant Sciences, 26(1): 34–39. Available at: http://www.thejaps.org.pk/docs/v-26-01/05.pdf

Wang H, Ni X, Qing X, Liu L, Lai J, Khalique A and Zeng D (2017). Probiotic enhanced intestinal immunity in broilers against subclinical necrotic enteritis. Frontiers in Microbiology, 8: 1–14. DOI:https://doi.org/10.3389/fimmu.2017.01592

Wang L, Lilburn M and Yu Z (2016). Intestinal microbiota of broiler chickens as affected by litter management regimens. Frontiers in Microbiology, 7: 1–12. DOI:https://doi.org/10.3389/fmicb.2016.00593

Wielen P, Keuzenkamp D and Lipman L (2002). Spatial and temporal variation of the intestinal bacterial community in commercially raised broiler chickens during growth. Microbial Ecology, 44(3): 286–293.DOI: https://doi.org/10.1007/s00248-002-2015-y

Yasothai R (2017). Importance of gut microflora in poultry. International Journal of Science, Environment, 6(1): 549–552.

Yegani M and Korver DR (2008). Factors affecting intestinal health in poultry. Poultry Science, 87(10): 2052–2063. DOI: https://doi.org/10.3382/ps.2008-00091

Yeoman C, Chia N, Jeraldo P, Sipos M, Goldenfeld N and White B (2012). The microbiome of the chicken gastrointestinal tract. Animal Health Research Review, 13(1): 89–99. DOI:https://doi.org/10.1017/S1466252312000138

Youssef IMI, Mostafa AS and Abdel-wahab MA (2017). Performance, intestinal microbiology and serum biochemistry of chicken. Journal of World's Poultry Research, 7(2): 57–71.

Zulkifli I, Abdullah N, Mohd-Azrin N and Ho Y (2010). Growth performance and immune response of two commercial broiler strains fed diets containing *Lactobacillus* cultures and oxytetracycline under heat stress conditions. British Poultry Science, 41(5): 593–597. DOI:https://doi.org/10.1080/713654979