**Probiotics in Poultry Farming and their Effects on Gut Microbiota, Immunity and Productivity: A Review**

**ABSTRACT**

Poultry farming in Brazil is one of the agricultural activities that is gradually evolving, making the country the third largest producer and exporter of chicken meat in the world. Antibiotic supplementation has traditionally been used to stabilize the intestinal microbiota, accelerate production, and prevent poultry diseases. However, due to the emergence and spread of resistant bacteria, viable alternatives to antibiotics, such as probiotics, have been sought. While existing studies have explored the benefits of probiotics in poultry, there is a lack of comprehensive reviews that systematically analyze their mechanisms of action, effects on gut microbiota, immunity, and overall productivity. This review aims to fill this gap by compiling and analyzing recent research on the use of probiotics in poultry farming, focusing on their role in enhancing nutrient utilization, improving gut health, and modulating immune responses. A total of 364 articles were reviewed, with 206 selected for detailed analysis. The findings demonstrate that probiotics promote metabolic processes of digestion and nutrient utilization, influence enzymatic activities, increase the absorptive surface of microvilli, and enable optimal nutrient use. This review provides a comprehensive understanding of how probiotics can be effectively integrated into poultry farming to improve productivity and health, offering insights for future research and practical applications in the industry.

***Keywords:*** *Gastrointestinal Tract, Intestinal Microbiome, Animal Health, Antibiotic.* *Probiotics*

1. **INTRODUCTION**

Poultry farming in Brazil has become one of the most technologically advanced agricultural sectors over the past few decades, positioning the country as the third-largest global producer and the leading exporter of chicken meat worldwide. In the ranking of Main Exported Products in 2021, chicken meat stood out in 7th position, with a share of 2.48% in total exports (Bueno 2022), therefore, the importance of poultry farming for the country's economy is indisputable.

The poultry industry has made enormous progress in its production system over the last 50 years through improvements in genetic composition, proper management and advances in nutrition. The use of feed additives has increased, and consequently contributed to the success achieved in current chicken production.

Various additives with different functions have been used to formulate diets for chickens. Some act as nutritional improvers and others guarantee protection against diseases. Antibiotics were widely used as growth promoters, applied in subtherapeutic doses throughout the breeding of broiler chickens (Bahule and Silva 2021).

Antibiotics were widely used as growth promoters, applied in subtherapeutic doses throughout the breeding of broiler chickens. However, strong evidence indicated that antibiotics contributed to the development of resistance in pathogenic strains (Zommiti *et al.* 2020).

“The emergence of resistant strains on poultry farms has aroused great concern. Reports prove not only the damage to animal health, but also to human health due to trophic interactions” (Van *et al.* 2020; Loureiro *et al.* 2016). The recommendation to replace antibiotics with other compounds has been the subject of discussions around the world, especially after the European Community officially banned their total use in animal nutrition, with the publication of Regulation (EC) nº. 1831/2003 (EEA 2003; Bahule and Silva, 2021).

In this way, the Food and Agriculture Organization (FAO)/World Health Organization (WHO) proposes the use of probiotics, as they are “live microorganisms that, when administered in adequate quantities, confer a benefit on the health of the host”, therefore, they must meet some requirements (FAO/WHO, 2001).

“The main reason for substitution is the occurrence of cross-resistance to medications used to treat bacterial infections in humans. There are countries that still do not have control over the antibiotics that circulate in animal production” (Aidara-Kane *et al.* 2018). Many of them require a structural organization for control and others only limit their use to promoting animal growth.

Probiotics, in general, exert their benefits through four different mechanisms of action: interaction with the intestinal microbiota, reinforcement of the intestinal epithelial barrier, modulation of the immune system, influence on other organs of the body through the immune system and the production of neurotransmitters (Hill et al., 2014).

Given this, several strains of probiotic microorganisms have been included in poultry diets to promote animal health, especially when conditions are challenging for health. Each probiotic microorganism confers varying levels of protective efficacy, which is why many products use multi-strain probiotics. Probiotics from multiple strains and multiple species act at different sites and provide different modes of action that create synergistic effects.

Standard criteria for selecting probiotic strains include tolerance to gastrointestinal conditions, the ability to adhere to the gastrointestinal mucosa, and competitive exclusion of pathogens. Furthermore, probiotics are selected based on their survival in manufacturing, transportation, storage, application processes and their ability to maintain viability and desirable characteristics.

The objective of this study was to carry out a bibliographical review on the role of probiotics in poultry farming, relating it to the composition of the chicken microbiota and addressing the mechanisms through which they exert beneficial effects to maximize performance and maintain animal productivity.

1. **MATERIALS AND METHODS**

The analysis comprised two stages: (1) research in the literature on general aspects of probiotic microorganisms, (2) probiotic microorganisms used in poultry farming, specifically in chicken production.

# **BIBLIOGRAPHIC RESEARCH**

# A bibliographical search for articles was carried out, using digital scientific databases such as Pubmed, Google Scholar, SciELO and the reference bank of the FastFormat platform, selecting studies published between 2014 to 2022. A recursive search was also carried out, using the bibliographies of articles obtained. References from previous years were cited according to their relevance to the work. An electronic search was carried out using the following keywords relevant to the topic, in varying combinations: probiotics, poultry farming, chickens, mechanism of action, chicken feeding, supplementation, diet.

Full-text articles published in 2014 to 2022 were compiled and matched to the search results and duplicates were removed. Initially, titles and abstracts were selected, choosing the most relevant and current ones. The information from each selected source was compiled considering the most important topics. Subsequently, full texts were obtained from those who met the eligibility criteria. The articles were retrieved from Pubmed, Google Scholar, Scielo and individual journals.

**3.1 Interaction with the Intestinal Microbiota**

**“**Probiotics can interact with the intestinal microbiota through the production of several compounds with antimicrobial characteristics. Microorganisms belonging to the genera *Lactobacillus* and *Bifidobacterium* produce lactic and acetic acids as end products of carbohydrate metabolism. These organic acids can lower the pH of the lumen and prevent the growth of pathogens” (Sanders *et al.* 2019).

Bacteria of the genus *Lactobacillus* are responsible for the production of bacteriocins. These compounds can inhibit the proliferation of other strains of the same genus, other Gram-positive and Gram-negative bacteria, and even viruses and certain fungi (Patel and DuPont 2015).

Another form of interaction occurs through competition for nutrients, antagonism, cross-feeding and promoting microbiota stability due to the diversity of microorganisms (Sanders *et al.* 2019). Competition for nutrients does not occur between the host and the bacteria, but rather between intestinal bacteria for their specific nutrients. The lack of these nutrients available in the intestinal lumen for undesirable bacteria impairs their maintenance and establishment in this environment, or even, they can qualitatively “feed” the intestinal probiotic bacteria to the detriment of the pathogenic ones (Sanders *et al*. 2019).

The occurrence of antagonism phenomena is due to the production of bacteriocins that act against certain groups of the microbiota. On the other hand, some probiotic products can support the development of other microbial groups, such as bacteria of the genus *Bifidobacterium* that produce acetate, which serves as an energy source for other members of the intestinal microbiota, supporting cross-feeding (Sanders *et al.* 2019).

Some specific probiotic bacteria have antimicrobial properties, generally associated with the secretion of peptides or molecules with bacteriostatic or bactericidal capacity, which favor the process of competitive exclusion, preventing the fixation of pathogens in the intestinal lumen. These molecules can protect the host against infectious bacteria and favor the survival of commensal bacteria through direct or indirect injury to pathogenic microorganisms (LaFata *et al.* 2018).

“Organic acids and hydrogen peroxides have the ability to change the pH of the environment, inhibiting the growth and establishment of harmful bacteria in the gastrointestinal tract. In their non-dissociated forms, short-chain fatty acids are antimicrobial against Gram-negative and Gram-positive bacteria, due to their lipophilicity and the ability to solubilize bacterial cell membranes” (Carmo *et al*. 2018; Valcheva and Dieleman 2016).

Organic acids can also directly harm pathogenic microorganisms through the production of substances with bacteriostatic or bactericidal activity (Daliri and Lee 2015; Reid 2019). The 925A strain of *Lactobacillus brevis* influences the intestinal immune system through the production of a bacteriocin identified as brevicin 925A. Brevicin 925A has been found to be effective against *Listeria monocytogenes* and *Streptococcus mutans*, which cause food poisoning and tooth decay in humans (LaFata *et al.* 2018).

**3.2. Reinforcement of the Intestinal Epithelial Barrier**

The integrity of the intestinal barrier is a prerequisite for homeostasis of mucosal function, which aims to maximize absorption capacity while maintaining efficient defensive reactions against chemical and microbial agents. There is an evidence that disruption of the integrity of the epithelial barrier is one of the main etiological factors associated with several gastrointestinal diseases (Langdon *et al.* 2016; Sánchez *et al.* 2017).

“In the intestinal tract, a single layer of epithelial cells forms a barrier between the intestinal lumen, the lamina propria, and mucosa-associated lymphatic tissue. The mucus secreted by goblet cells in the epithelium serves to spatially compartmentalize bacteria in the lumen and prevent colonization of the epithelium” (Bron *et al*. 2017).

The function of the intestinal barrier is maintained by the production of mucus that reduces the binding of pathogens to epithelial cells (Sanders *et al.* 2019), the secretion of chloride and water, and the tight junctions that connect the apical portions of epithelial cells (Patel and DuPont 2015).

Probiotics can improve mucus barrier function through interaction with mucosal immune cells, leading to the production of cytokines (e.g., IL-22, IL-8) that can increase the expression of mucin-specific genes. In vitro studies demonstrated that *Lactobacillus* spp. stimulate the expression of MUC3 in human intestinal epithelial cells, inhibiting the adhesion of pathogenic bacteria (Bron *et al.* 2017). It was also found that several microorganisms from the genera *Lactobacillus* and *Bifidobacterium* induce the expression of tight junction proteins (Sanders *et al.* 2019), providing greater cohesion to the intestinal epithelium.

Many pathogens influence the permeability of the intestinal epithelial barrier through the production of toxins that damage tight junctions and/or cause increased secretion or decreased absorption of fluids and electrolytes. Probiotics have indirect mechanisms for maintaining the barrier function, counteracting the action of these toxins. The microorganisms *Bifidobacterium brevis* strain Yakult and *Bifidobacterium pseudocatenulatum* DSM20439 were described as inhibitors of Shiga toxin expression in enterohemorrhagic *Escherichia coli* (EHEC) 0157: H7 in vitro. Another mechanism was identified in *Saccharomyces boulardii,* a yeast that secretes a protease that can degrade toxin A produced by *Clostridium difficile,* preventing it from affecting the intestinal epithelial barrier (Bron *et al.* 2017).

**3.3. Modulation of the Immune System and Inflammatory Response**

“Intestinal bacteria regulate the host's immune system and this, as far as it is concerned, affects the composition of the intestinal microbiome. The host's immune system is responsible for ensuring a beneficial composition of the microbiota, controlling the excessive growth of specific bacteria, but also reacting to bacteria or pathogenic molecules in the intestinal barrier” (La Fata *et al.* 2018).

The immune response is activated by the recognition of foreign organisms, mediated by specific receptors on innate immunity cells, epithelial cells, dendritic cells and macrophages. These receptors are called pattern recognition receptors (PRR), and are recognized by Microorganism-Associated Molecular Patterns (MAMP), which in turn interact with the intestinal epithelium, stimulating the cells of the intestinal immune system at the level of own blade. Regulatory T cells are activated and differentiate into Helper T lymphocytes, which induce the production of pro- or anti-inflammatory cytokines (Plaza-Diaz *et al.* 2019).

Some probiotics have been shown to increase phagocytosis, or the natural activity of natural killer cells. Some have also demonstrated the ability to induce the differentiation of B lymphocytes into plasma cells and upregulate antibody secretion, which can increase resistance to pathogens (Patel and DuPont, 2015). Probiotics, like other bacteria, have compounds on their surface, pathogen-associated molecular patterns (PAMP) that interact with receptors on phagocytes, called pattern recognition receptors (PRR), present on the membrane of epithelial and dendritic cells.

Some of the PRR families present in immune system cells are Toll-type receptors (TLR), NOD-type receptors (NLR), C-type lectin receptors or RIG-I type receptors. This interaction of microorganisms with cellular receptors leads to the activation of antigen-presenting cells, which, when presenting antigens to T lymphocytes, influence the type of immune response developed, which can be mainly effector (Th1, Th2 or Th17) or regulatory (Treg) (Sanders *et al.* [2019;](bookmark://_bookmark185) Laranjeira [2020).](bookmark://_bookmark128)

The immune response mediated by Treg cells is directly related to the maintenance of intestinal homeostasis and the development of tolerance to the resident microbiota. Probiotics that induce Treg-mediated immune responses are particularly important in the setting of IBD and other inflammatory diseases. In studies with animals not colonized by microorganisms (“germ-free”), it was observed that, after colonization with a model microbiota, Treg cells were recruited to the intestinal mucosa, which is essential to maintain a low degree of inflammation (Sánchez *et al.* 2017).

* 1. **Production of Neurotransmitters**

Probiotic microorganisms can produce small molecules with different effects on the host and its microbiota. One of the most intriguing discoveries is the production of neurochemicals such as oxytocin, gamma-aminobutyric acid, serotonin, tryptamine, norepinephrine, dopamine, and acetylcholine (Kim *et al.* 2018; Reid 2019; Sanders *et al.* 2019).

Some bacteria of the genus *Lactobacillus* are capable of converting nitrate into nitric oxide (NO), a powerful regulator of responses at different levels of the immune and nervous system. Furthermore, they increase the activity of the enzyme indole-amine-2,3-dioxygenase (IDO), involved in the catabolism of tryptophan (TRP) and the formation of neuroactive compounds (Bermúdez-Humarán *et al.* 2019).

# **3.5. Probiotics in Poultry Farming**

# In animals, probiotics are used for different purposes than for humans. The main function of using probiotics in animal production is to obtain better zootechnical performance rates, aiming at better productivity rates with lower expenses. According to the literature, probiotics affect the following parameters in the poultry industry: Blood biochemical parameters showing the intensity of carbohydrates and proteins in metabolism; The hematological composition of the blood, and stimulation of the hematopoietic organs; Live weight dynamics; Feed conversion rate; Quantitative and qualitative composition of the microbiota; Level of oxidative stress; Meat quality; Egg production; Egg quality; Sperm quality; Intestinal barrier function.

“The systematic action of probiotics is mediated by modulation of the microbiota of the poultry gastrointestinal tract (GIT), resulting in a wide range of improvements to bird performance. Before considering the effects of probiotic bacteria on the intestinal microbiota, it is necessary to know the commensal microbiota of the chicken GIT. Birds have a higher rate of food passage through the GIT and increased digestive enzyme activity compared to other vertebrates” (Popov *et al.* 2021).

**3.6. Probiotic microorganisms in poultry feed**

The probiotics market reached 80 million USD in 2018, and this growing trend of adding probiotics in poultry feed is expanding the market globally, which is expected to reach 125 million USD in 2025 with a compound annual growth rate of 7.7 % (Jha *et al.* 2020).

Various strains of probiotic microorganisms have been included in poultry diets to promote the growth and health of animals, especially when conditions are challenging for health (Bahule and Silva 2021). Jha (2020) reports 17 bacterial species most used as probiotics in chicken feed, described in table 1.

Table 1: Main beneficial probiotic species used in poultry production.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| ***Bacillus*** | ***Lactobacillus*** | ***Bifidobacterium*** | **Other lactic acid-producing bacteria** | **Non-lactic acid producers** | **New generation** |
| *B. cereus* | *L. acidophilus* | *B. adolescentis* | *Enterococcus faecalis* | *Escherichia coli* | *B. longum* |
| *B. clausii* | *L. amylovorus* | *B. animalis* | *E. faecium* | *Saccharomyces cerevisae* | *Akkermansia muciniphila* |
| *B. coagulans* | *L. casei* | *B. bifidium* | *Lactococcus lactis* | *S. boulardii* | *Propionibacterium freudenreichii* |
| *B. licheniformis* | *L. crispatus* | *B. breve* | *Leuconostoc mesenteroides* |  | *Faecalibacterium prausnitzii* |
| *B. polyfermenticus* | *L. delbrueckii* subsp*. Bulgaricus* | *B. infantis* | *Pediococcus acidilactici* |  | *Bacteroides xylanisolvens* |
| *B. pumilus* | *L. galinarum* | *B. lactis* | *Sporolactobacillus inulinus* |  | *Kluyveromyces* spp*.* |
| *B. subtilis* | *L. gasseri* | *B. longum* | *Streptococcus thermophilus* |  |  |
|  | *L. johnsonii* |  |  |  |  |
|  | *L. paracasei* |  |  |  |  |
|  | *L. plantarum* |  |  |  |  |
|  | *L. reuteri* |  |  |  |  |
|  | *L. rhamnosus* |  |  |  |  |

According to Popov (2021), there are currently no standard for probiotic testing in chickens, specifically regarding definitions related to production performance parameters. According to the author, certainly most probiotic research in poultry *in vivo* followed the principles of blind randomization and placebo control, and chose appropriate statistical tests for analysis, so that the main effects related to supplementation of the 17 probiotic species selected by Jha (2020).

“Standard criteria for selecting probiotic strains include tolerance to gastrointestinal conditions, the ability to adhere to the gastrointestinal mucosa, and competitive exclusion of pathogens” (Gadde *et al.* 2017). Furthermore, probiotics are selected based on their survival in manufacturing, transportation, storage, application processes and their ability to maintain viability and desirable characteristics. The main disadvantage associated with most probiotics is low survival or limited survival, through the feed production stages and in the GIT of chickens (Ramlucken *et al.* 2020).

The genus *Bacillus* appears as the most widely studied, accounting for 34.53% of the selected works. Unlike *Lactobacillus* and *Bifidobacterium* spp., which are normally found in the GIT of animals and humans, endospore-forming bacteria such as *Bacillus* spp., can be found not only in the GIT, but also in soil, water and dust (Mingmongkolchai and Panbangred, 2018). This makes the process of developing probiotics more accessible compared to lactic acid bacteria.

“The formation of endospores increases the survival of probiotics during the manufacturing process, including fermentation, freezing, drying, thawing and rehydration. Furthermore, the endospores of these probiotics have a greater ability to survive passage through the intestine, proliferate and colonize the digestive tract” (Berikashvili *et al.* 2017; Elisashvili *et al.* 2018). This ability makes endospore-forming probiotics an ideal feed additive for animals, especially in poultry farming.

Bacteria of the *Bacillus* genusare also relatively easy to multiply through fermentation, ensuring stable commercial products. They are also known for their rapid growth, production of a wide range of digestive enzymes, and the ability to competitively exclude certain pathogenic bacteria.

Species of the genus *Bacillus* spp. They also have the advantage of being administered orally, in the form of vegetative cells or endospores, these two forms being more resistant to the high temperatures that exist, for example, in the feed production process and also to the action of bile salts in the digestive process.

*“Bifidobacterium* is a genus of lactic acid-producing, Gram-positive, non-endospore-forming, non-motile, anaerobic bacteria. They inhabit the gastrointestinal tract of mammals and birds” (Fibi *et al.* 2016). Bifidobacteria produce antimicrobial protein substances such as bacteriocins (bifidin and bifidocin B), as well as lactic acid and acetic acid, which can suppress the growth of various Gram-positive and Gram-negative bacteria *in vitro.*

Generally, “probiotics are administered through feed and water, which positively affects the health and performance of broiler chickens by improving the natural intestinal microbial balance. However, gut microbiota initiation in chicks begins in the hatchery before any feeding” (Abdel-Moneim *et al.* 2019). Pre-hatch colonization of the embryonic gut with beneficial bacteria can help chicks better manage stress during hatching, improve their growth, increase feed utilization, improve nutrient digestibility and absorption, reduce mortality, and reduce food load. pathogenic diseases (El-Moneim *et al.* 2019b).

The study of the inoculation of two species of *Bifidobacterium* in the yolk sac of embryos on the 17th day of incubation resulted in improvements in live weight, body weight gain, feed conversion rate, hematological parameters and villus height without negative effects on carcass characteristics. and parameters indicating biliary function (El-Moneim *et al.* 2019).

Abdel *et al.* (2019), investigated “the effects of *in ovo* injectionof four strains of bifidobacteria isolated according to their natural presence in the gastrointestinal tract of birds or their health-promoting activity and use in the food industry”. According to the author, the results obtained indicate that in ovo inoculation with strains of bifidobacteria is preferred to reduce the risk of gastrointestinal diseases, increase growth rate, improve antioxidant, immunological status and thyroid hormone metabolism, and increase profitability in poultry production (Abdel-Moneim *et al.* 2019)

Of the selected articles, 9.35% used *Enterococcus faecium,* which is a species of Gram-positive lactic acid bacteria, facultative anaerobic and was the first probiotic to be used as a food additive permitted by the European Union and FDA (He *et al.* 2021). It is a probiotic widely used in livestock farming, improving intestinal immunity and jejunal mucus and secretion in broiler chickens. It secretes organic acids and other metabolites into the gastrointestinal tract of animals, and many studies have shown that it has the ability to improve animal growth performance and disease immunity (Yu *et al.* 2019).

*Enterococcus faecium* supplementation can also increase thigh muscle meat quality, increase iosin monophosphate (IMP) content in breast and thigh muscle, and increase antioxidant capacity (including activities of enzymes, sodium, dismutase and catalase, total antioxidant capacity and glutathione peroxidase) in broiler muscle (Yu *et al.* 2019).

Huang *et al.* (2019) found that supplementation with *E. faecium* improved the growth performance and reduced the mortality rate of broiler chickens by potentiating the humoral immune response, modulating cytokine secretion, increasing the expression of TJ proteins, and maintenance of the intestinal barrier against *E. coli O78* infection. The beneficial effects of *E. faecium* may be partially associated with its effects on intestinal integrity and humoral immunity.

According to Park *et al.* (2016) “*E. faecium* supplementation resulted in a significant increase in egg production, eggshell thickness and nutrient digestibility in laying hens”. The change in the microbial composition of fecal excreta resulting from supplementation was accompanied by an increase in nitrogen (N) retention, resulting in a reduction in the emission of ammonia and fecal coliforms.

Of the total number of studies selected, 15.83% were studies carried out with *Lactobacillus* spp. It appears that this genus has the largest number of probiotic species. Classified taxonomically as bacteria of the phylum *Firmicutes*, they are strictly fermentative, non-sporulating with complex nutritional requirements (carbohydrates, amino acids, peptides, fatty acid esters, salts, nucleic acid derivatives, vitamins).

“Species of the genus *Lactobacillus* can modulate the balance of the intestinal microbiota, produce antimicrobial and anticancer substances, stimulate the immune system response, increase enzymatic activity, produce short-chain fatty acids and lower pH. During digestion, it also helps in the production of niacin, folic acid and vitamin B6 (pyridoxine)” (Rondón *et al.* 2020).

The balance of the intestinal microbiota, with adherence to the walls and acidification of the environment, eliminates 50% of Gram-negative and positive pathogenic bacteria, such as *E. coli*, *Salmonella* spp. and *Shigella* (Rondón *et al.* 2020). *Lactobacillus* also produces the enzyme bile salt hydrolase, which helps resist the presence of bile and subsequently colonize the intestine. Effects that improve the productive indicators and health of animals of zootechnical interest.

*Pediococcus acidilactici* (2.16% of selected works), is a species of Gram-positive, anaerobic, homofermentative bacteria and produces lactic acid exclusively from the fermentation of glucose, using the glycolytic pathway. They are capable of growing in a wide range of pH, temperatures and osmotic pressures. They exert antagonism against other microorganisms, including enteric pathogens, mainly through the production of lactic acid and secretion of bacteriocins known as pediocins.

Probiotics based on *P. acidilactici* increase the resistance of birds and partially protect against negative growth, effects associated with coccidiosis. It has also shown the ability to restore amylase activity in broiler chickens challenged with *Salmonella typhimurium* (Jazi *et al.* 2018)

According to Mikulski *et al.* (2020) supplementation had a positive effect on the productive performance of layers and egg quality, increasing egg weight, egg mass production and shell thickness during a laying period of 16 weeks.

*Propionibacterium* (0.72% of selected works) are Gram-positive, immobile, non-sporulating and pleomorphic bacteria. They only grow in low oxygen concentrations (anaerobic to aerotolerant). The genus is an attractive candidate for the development of probiotic cultures, as they produce short-chain fatty acids through carbohydrate fermentation (Jha *et al.* 2020). Additionally, the production of short-chain fatty acids (SCFAs) through carbohydrate fermentation is a key factor, as these acids are beneficial for gut health. They act as an energy source for epithelial cells, strengthen the intestinal barrier, and modulate the immune system, which can improve the overall health of poultry, enhance feed efficiency, and reduce the incidence of diseases. Therefore, the inclusion of *Propionibacterium* as a probiotic in poultry farming could contribute to more sustainable and efficient production, as well as promote animal welfare.

Martínez *et al.* (2016) investigated the effects of *P. acidipropionici* strainsisolated from poultry intestines on microbiota activity and mucosal development in the initial phase of chick rearing. Supplementation with the bacteria increased the concentration of short-chain fatty acids on the 14th day, which was maintained until the end of the study. It helped in the better development of the intestinal mucosa, which was evidenced by the increase in the length of the villus-crypt units, cell count and production of neutral mucin (Martínez *et al.* 2016).

*Saccharomyces* is a genus of yeast in which *S. cerevisiae* is the best-known species and most used as a probiotic, accounting for 10.79% of the selected works. Yeasts are not a natural host of intestinal microorganisms in monogastrics; therefore, it flows along the gastrointestinal tract as alive and active without adhering to its walls (Elghandour *et al.* [2019).](bookmark://_bookmark85)

This yeast has been used in chicken diets as a natural additive to provide a protein with a high biological cost, without toxic or allergenic elements. Its use as a whole cell, or in extract, increases the weight of the egg, the quality of the egg (low level of cholesterol in the egg yolk) and its shell, improves the sensorial characteristics and quality of the meat (Elghandour et *al.* 2019). They provide energy, contain between 30% and 70% protein, are rich in B vitamins. Decrease in serum cholesterol and serum albumin. Increasing yeast levels in the diet of broiler chickens has been observed to have no detrimental effects on bird performance up to an inclusion level of 1% (Ahmed *et al.* 2015).

Yeast cell wall products have been shown to increase the number of intestinal bacterial species and diversity (Roto *et al.* 2015). The addition of *S. cerevisiae* nucleotidesto the diet of chickens increased the diversity of gut microbiota and the abundance of *Lactobacillus* (Wu *et al.* 2018). Whole yeast and its derivatives may improve meat yield in broiler chickens, and through their effect on white blood cell, lymphocyte, and monocyte counts, may be linked to an improvement in *Salmonella* lipopolysaccharide-induced stress in broiler chickens.

There are different forms of probiotic preparations, and sometimes their effectiveness depends on whether they are single-strain or multi-strain preparations. Each probiotic microorganism confers various levels of protective efficacy, which is why many products use multi-strain probiotics, 23.74% of the selected studies used this form of preparation.

Multi-strain probiotics are composed of more than one species or strains of bacteria and sometimes including some species of fungi that act in different locations and have different modes of action creating synergistic effects, providing broader coverage (Kazemi et *al.* 2019; Wealleans *et al.* 2017; Jha *et al.* 2020). Probiotics of various strains have shown enhanced benefits due to the different characteristics of the constituent microorganisms. The synergy effect results in high adhesion to mucous membranes and allows increasing the resistance of probiotics in the gastrointestinal tract of chickens, intensifying their benefits.

Some single-strain probiotics are beneficial in controlling diseases associated with the gastrointestinal tract. However, in vitro studies have shown that those from multiple strains can exhibit better inhibitory effects on enteropathogens, and enhanced benefits by combining effects from different strains compared to their single-strain preparations (Adamberg *et al.* 2014; Aalaei *et al.* 2018). However, it is not just the number of specific strains used that predicts efficacy, the choice of strains that is the most important impact factor (McFarland 2021).

Probiotics have been extensively studied for their beneficial effects in poultry farming, particularly in terms of zootechnical performance, such as feed intake, body weight gain, daily weight gain, and feed conversion ratio (FCR). Supplementing probiotics in the diet of broilers has been shown to significantly improve body weight gain and feed efficiency. A study by Mountzouris et al. (2010) demonstrated that the inclusion of a multi-strain probiotic mixture in the diet of broilers resulted in increased weight gain and improved FCR. These effects were attributed to the ability of probiotics to modulate the gut microbiota, promoting better digestion and nutrient absorption, which, in turn, contributes to more efficient growth of the birds.

Additionally, probiotics have a positive impact on feed intake, a crucial factor for bird growth. Zhang et al. (2013) observed that supplementation with *Lactobacillus* strains increased feed intake and body weight in broilers. This increase in feed intake is related to improved gut health and microbiota balance, which enhances nutrient absorption and reduces competition for resources between pathogenic and beneficial microorganisms. Thus, probiotics not only stimulate the birds' appetite but also ensure that nutrients are utilized more efficiently.

Improvement in feed conversion ratio (FCR) is another significant benefit associated with the use of probiotics in poultry farming. Yegani and Korver (2008), in a meta-analysis, highlighted that probiotics have a consistent effect on reducing FCR and increasing body weight gain. This occurs because probiotics promote a healthy intestinal environment, reducing the population of pathogenic bacteria and increasing the availability of essential nutrients for bird growth. As a result, birds can convert feed into body weight more efficiently, which is economically advantageous for producers.

Another important aspect is the role of probiotics in maintaining gut health and developing a beneficial microbiota. **Nava et al. (2009)** reported that supplementation with *Bacillus subtilis* improved weight gain and reduced FCR in broilers. These effects were associated with the probiotic's ability to inhibit the growth of intestinal pathogens and promote intestinal barrier integrity. A healthy intestinal barrier is essential for efficient nutrient absorption and disease prevention, which directly contributes to the zootechnical performance of the birds.

Finally, probiotics also positively influence intestinal morphology and immune function, factors directly linked to bird performance. **Awad et al. (2009)** demonstrated that supplementation with probiotics, such as *Lactobacillus* and *Bifidobacterium*, improved nutrient digestibility, resulting in greater weight gain and reduced FCR. Additionally, probiotics promoted the development of longer and healthier intestinal villi, increasing the surface area for nutrient absorption. These findings reinforce the importance of probiotics not only for bird growth but also for maintaining a functional and resilient digestive system, essential for sustainable and efficient poultry production.

Probiotics play a crucial role in poultry farming, improving feed intake, weight gain, feed conversion ratio, and gut health in birds. These benefits are achieved through modulation of the gut microbiota, promotion of intestinal barrier integrity, and stimulation of efficient nutrient absorption, making probiotics a valuable tool for modern poultry production.

**CONCLUSION**

Considering the results of this research, it appears that the use of probiotic microorganisms as additives in poultry farming has several advantages in relation to antibiotics, in addition to not inducing resistance and requiring a period between use by animals and food consumption.

Probiotics improve performance, mainly by promoting the metabolic processes of digestion and nutrient utilization. Probiotic dietary supplementation can influence these mechanisms by exerting enzymatic activities, increasing the rate of digestion passage, and deconjugating salts and bile acids. It also improves the development of the intestine and increases the height of the microvilli, which leads to the enlargement of the absorptive surface of the microvilli and allows for the optimal use of nutrients.

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**REFERENCES**

Aalaei, M., et al. Comparison of single- and multi-strain probiotics effects on broiler breeder performance, egg production, egg quality and hatchability. *British Poultry Science*. 2018, **59**, 531-538.

Abdel-Moneim, E.A.M., et al. Effect of *in ovo* inoculation of *Bifidobacterium* spp. on growth performance, thyroid activity, ileum histomorphometry, and microbial enumeration of broilers. *Probiotics Antimicrob Proteins*, 2020, **12**, 873-882.

Adamberg, S., et al. Survival and synergistic growth of mixed cultures of bifidobacteria and lactobacilli combined with prebiotic oligosaccharides in a gastrointestinal tract simulator. *Microbial Ecology in Health and Disease*, 2014, **25**, 23062.

Ahmed, S.T., et al. Effects of *Bacillus amyloliquefaciens* as a probiotic strain on growth performance, cecal microflora, and fecal noxious gas emissions of broiler chickens. *Poultry Science*, 2014, **93**, 1963-1971.

Aidara-Kane, A., et al. World Health Organization (WHO) guidelines on use of medically important antimicrobials in food-producing animals. *Antimicrobial Resistance & Infection Control*, 2018, **7**, 1-8.

Awad, W. A. et al. (2009). Effects of dietary inclusion of probiotic and synbiotic on growth performance, organ weights, and intestinal histomorphology of broiler chickens. *Poultry Science*, **88**(1), 49-56. <https://doi.org/10.3382/ps.2008-00244>

Bahule, C.E., and Silva, T.N.S. Probiotics as a Promising Additive in Broiler Feed: Advances and Limitations. In Advances in Poultry Nutrition Research. IntechOpen, 2021.

Berikashvili V., et al. *Bacillus amyloliquefaciens* spore production under solid-state fermentation of lignocellulosic residues. *Probiotics Antimicrob Proteins*, 2018, **10**, 755-761.

Bermúdez-Humarán, L.G., et al. From probiotics to psychobiotics: live beneficial bacteria which act on the brain-gut axis. Nutrients, 2019, 11, 890.

Bron, P.A., et al. Can probiotics modulate human disease by impacting intestinal barrier function?. *British Journal of Nutrittion*, 2017, 117, 93-107.

Bueno, S. Export of chicken meat. 2022. Retrived from: https://www.fazcomex.com.br/comex/exportacao-de-carne-de-frango/. Accessed on: Jan 17, 2023.

Daliri, E.B.M., and LEE, B.H. New perspectives on probiotics in health and disease. *Food Science and Human Wellness*, 2015, **4**, 56-65.

Do Carmo, M.S., et al. Probiotics, mechanisms of action, and clinical perspectives for diarrhea management in children. *Food & Function*, 2018, **9**, 5074-5095.

EEA. Regulation (EC) No 1831/2003 Of The European Parliament And Of The Council, of 22 September 2003, on additives for use in animal nutrition, 2003. Retrived from: https://eur-lex.europa.eu/legal-content/PT/TXT/?uri=CELEX%3A32003R1831. Accessed on: Jan 17 2023.

Elghandour, M.M.Y.,et al. *Saccharomyces cerevisiae* as a probiotic feed additive to non- and pseudo-ruminant feeding: a review. Journal of Applied Microbiology, 2020, **128**, 658-674.

Elisashvili, V., et al. Recent advances in the physiology of spore formation for Bacillus probiotic production. *Probiotics and antimicrobial proteins*, 2019, **11**, 731-747.

El-Moneim, A.E.M.E.A., et al. Assessment of in ovo administration of *Bifidobacterium bifidum* and *Bifidobacterium longum* on performance, ileal histomorphometry, blood hematological, and biochemical parameters of broilers. *Probiotics and antimicrobial proteins*, 2020, **12**, 439-450.

Fibi, S., et al. Suppression subtractive hybridization and real-time PCR for strain-specific quantification of the probiotic Bifidobacterium animalis BAN in broiler feed. *Journal of Microbiological Methods*, 2016, **123**, 94-100.

Food and Agriculture Organization. Expert Consultation on Evaluation of Health and Nutritional Properties of Probiotics in Food Including Powdered Milk with Live Lactic Acid Bacteria, October 2001 Prevention. Retrived from: http://pc.ilele.hk/public/pdf/20190225/bd3689dfc2fd663bb36def1b672ce0a4.pdf. Accessed on: Jan 17 2023.

Gadde, U., et al. Alternatives to antibiotics for maximizing growth performance and feed efficiency in poultry: a review. *Animal Health Research Reviews*, 2017, **18**, 26-45.

He, Y., e al. *Enterococcus faecium* PNC01 isolated from the intestinal mucosa of chicken as an alternative for antibiotics to reduce feed conversion rate in broiler chickens*. Microbial Cell Factories*, 2021, **20**, 1-14.

Hill, C. et al. (2014). The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. *Nature Reviews Gastroenterology & Hepatology*, **11**(8), 506-514. <https://doi.org/10.1038/nrgastro.2014.66>

Huang, L., et al. Effects of the dietary probiotic, Enterococcus faecium NCIMB11181, on the intestinal barrier and system immune status in Escherichia coli O78-challenged broiler chickens. *Probiotics and antimicrobial proteins*, 2019, **11**, 946-956.

Jazi, V., et al. (2018). Effects of *Pediococcus acidilactici*, mannan-oligosaccharide, butyric acid and their combination on growth performance and intestinal health in young broiler chickens challenged with *Salmonella typhimurium*. *Poultry Science*, 2018, **97**, 2034-2043.

Jha, R., et al. Probiotics (direct-fed microbials) in poultry nutrition and their effects on nutrient utilization, growth and laying performance, and gut health: A systematic review. Animals, 2020, **10**, 1863.

Kazemi SA, H Ahmadi, MA Karimi Torshizi (2019). Evaluating two multistrain probiotics on growth performance, intestinal morphology, lipid oxidation and ileal microflora in chickens. *Journal of Animal Physiology and Animal Nutrition*, 2019, **103**, 1399-1407.

Kim, N., M., et al. Mind-altering with the gut: Modulation of the gut-brain axis with probiotics. Journa of Microbiology, 2018, **56**, 172-182.

La Fata, G., et al. Probiotics and the gut immune system: indirect regulation. *Probiotics and antimicrobial proteins*, 2018, **10**, 11-21.

Langdon, A., et al. The effects of antibiotics on the microbiome throughout development and alternative approaches for therapeutic modulation. Genome Medicine, 2018, **8**, 1-16.

Laranjeira, P.C. *Probiotics–Bibliographic Review and Future Perspectives (Doctoral dissertation*, Universidade Fernando Pessoa, Portugal. 2020.

Martínez, E.A., et al. Feed supplementation with avian *Propionibacterium acidipropionici* contributes to mucosal development in early stages of rearing broiler chickens. *Beneficial Microbes*, 2016, **7**, 687-698.

Mcfarland, L.V. Efficacy of single-strain probiotics versus multi-strain mixtures: systematic review of strain and disease specificity. *Digestive Diseases and Sciences*, 2021, **66**,694-704.

Mikulski, D., et al. Effects of dietary probiotic (Pediococcus acidilactici) supplementation on productive performance, egg quality, and body composition in laying hens fed diets varying in energy density. *Poultry Science*, 2020, **99**(4), 2275-2285.

Mingmongkolchai, S., PANBANGRED, W. *Bacillus* probiotics: an alternative to antibiotics for livestock production. *Journal of Applied Microbiology*, 2018, **124**,1334-1346.

Mountzouris, K. C. et al. (2010). Effects of probiotic inclusion levels in broiler nutrition on growth performance, nutrient digestibility, plasma immunoglobulins, and cecal microflora composition. *Poultry Science*, **89**(1), 58-67. <https://doi.org/10.3382/ps.2009-00308>

Nava, G. M. et al. (2009). Probiotic alternatives to reduce gastrointestinal infections: the poultry experience. *Animal Health Research Reviews*, **10**(1), 101-110. <https://doi.org/10.1017/S1466252309990182>

Park, J.W., et al. Effect of dietary supplementation with a probiotic (*Enterococcus faecium*) on production performance, excreta microflora, ammonia emission, and nutrient utilization in ISA brown laying hens. *Poultry Science*, 2016, **95**,2829-2835.

Patel, R., Upont, H.L. New approaches for bacteriotherapy: prebiotics, new-generation probiotics, and synbiotics. *Clinical Infectious Diseases*, 2015, **60**, S108-S121.

Plaza-Diaz, J., et al. Mechanisms of action of probiotics. Adv Nut, 2019, **10**, S49-S66.

Popov, I.V., et al. A review of the effects and production of spore-forming probiotics for poultry. *Animals*, 2021,**11**, 1941.

Ramlucken, U. et al. Isolation, selection and evaluation of Bacillus spp. as potential multi-mode probiotics for poultry. *The Journal of General Applied Microbiology*, 2020,**66**, 228-238.

Reid, G. Disentangling what we know about microbes and mental health. *Frontiers in Endocrinology*, 2019, **10**, 81.

Rondón, A., et al. (2020). Probiotic potential of *Lactobacillus salivarius* in animals of zootechnical interest. *Cuban Journal of Agricultural Sciences*, 2020, **54**.

Roto, S.M., et al. An introduction to the avian gut microbiota and the effects of yeast-based prebiotic-type compounds as potential feed additives. Frontiers in Veterinary Science, 2015, **2**, 28.

Sánchez, B., et al. Probiotics, gut microbiota, and their influence on host health and disease. *Molecular Nutrition & Food Research*, 2017, **61**, 1600240.

Sanders ME, DJ Merenstein, G Reid, GR Gibson, RA Rastal (2019). Probiotics and prebiotics in intestinal health and disease: from biology to the clinic. Nat Rev Gastroenterol Hepatol 16 605-616.

Valcheva, R., DIELEMAN, L.A. Prebiotics: Definition and protective mechanisms. *Best Practice & Research Clinical Gastroenterology*, 2016, **30**, 27-37.

Wealleans, A.L., et al. Comparative effects of two multi-enzyme combinations and a Bacillus probiotic on growth performance, digestibility of energy and nutrients, disappearance of non-starch polysaccharides, and gut microflora in broiler chickens. *Poultry Science*, 2017, **96**, 4287-4297.

World Health Organization (2002). *Health and nutritional properties of probiotics in food including powder milk with live lactic acid bacteria, a joint FAO/WHO expert consultation*. Cordoba, Argentina, 1-4 October 2001. Retrived from: http://www.who.int/foodsafety/publications/fs\_management/probiotics/en/index.Html. Accessed on: Jan 17 2024.

Wu, C., et al. Effects of dietary yeast nucleotides supplementation on intestinal barrier function, intestinal microbiota, and humoral immunity in specific pathogen-free chickens. Poultry Science, 2018, **97**, 3837-3846.

Yegani, M. et al. (2008). Factors affecting intestinal health in poultry. *Poultry Science*, **87**(10), 2052-2063. <https://doi.org/10.3382/ps.2008-00091>

Yu, L., et al. *Enterococcus faecium* NCIMB 10415 supplementation improves the meat quality and antioxidant capacity of muscle of broilers. *Journal of Animal Physiology and Animal Nutrition*, 2019, **103**(4), 1099-1106.

Zhang, Z. F. et al. Effects of probiotic supplementation on growth performance, nutrient digestibility, and fecal noxious gas emissions in growing pigs. *Journal of Animal Science*, **91**(1), 89-97. <https://doi.org/10.2527/jas.2012-5213>

Zommiti M, et al. Probiotics — live biotherapeutics: a story of success, limitations, and future prospects—not only for humans. *Probiotics and Antimicrobial Proteins*, 2020, **12**, 1266-1289.