***Review Article***

**Emerging Trends in the Use of Nutraceuticals for Improved Poultry Production**

**ABSTRACT**

The rising demand for safe and high-quality poultry products has led to the exploration of nutraceuticals as viable alternatives to antibiotic growth promoters (AGPs). The term "nutraceutical," introduced by Dr. Stephen DeFelice in 1989, refers to bioactive compounds derived from food that offer health benefits beyond basic nutrition. The global nutraceutical market, valued at USD 291.33 billion in 2022, is projected to grow at a CAGR of 9.4% (2023–2030), driven by consumer awareness and the need for antibiotic-free poultry production. Excessive antibiotic use in poultry farming has been linked to antimicrobial resistance, residue contamination, and environmental risks, posing threats to both animal and human health. In contrast, nutraceuticals—including probiotics, prebiotics, phytobiotics, amino acids, antioxidants, fatty acids, and functional foods—support gut health, enhance immunity, improve feed efficiency, and help mitigate stress-related challenges in poultry. Unlike Antibiotic growth promoters, nutraceuticals promote growth without disrupting the microbiota or contributing to resistance. This review, based on modern scientific research, examines the various types of nutraceuticals, their mechanisms of action, and their effects on poultry health, productivity, and food safety. Additionally, it highlights their role in ensuring sustainable poultry production while reducing dependence on antibiotics.

**Keywords:** Broilers, Phytobiotics, Probiotics, Antioxidants, Spirulina, Curcumin, Fatty Acids

**1. INTRODUCTION**

Over the past four decades, poultry production in India has undergone a remarkable transformation, shifting from traditional farming methods to a technologically advanced commercial production system. Currently the total Poultry population in our country is 851.81 million. Chicken meat has become one of the most affordable sources of high-quality lean protein. In 2023/2024, global production reached 103.83 million metric tonnes, as reported by the USDA Foreign Agricultural Service’s “Livestock and Poultry: World Markets and Trade.” In 2020, poultry accounted for nearly 40% of global meat production. The United States is the leading producer, responsible for 20% of global output, followed by Brazil and China, each with 14%. According to the United Nations Food and Agriculture Organization, pork is the most consumed meat worldwide, making up 36% of global consumption, followed by poultry at 33%, beef at 24%, and goats/sheep at 5%. Antibiotic growth promoters (AGP) have been used in broilers to increase live weight and feed efficiency (Diaz et al. 2019). However, its use in poultry feed has been restricted in Europe and the United States because it may promote the growth of antibiotic-resistant bacterial strains, resulting in antimicrobial resistance. The Government of India also banned the use of antibiotic growth promoters (AGPs) in layer feed on February 27, 2023 and the Food Safety and Standards Authority of India (FSSAI) announced a ban on the use of antibiotics in poultry and other food animals at all stages of production, including milk, meat, poultry, eggs, and aquaculture from April 1, 2025. The safety of animal-derived foods has been called into question in recent years due to outbreaks of zoonotic diseases and food-borne bacterial infections, increased veterinary drug residues in poultry products, and antibiotic-resistant microbial growth. These instances have forced health professionals and veterinarians to actively monitor any food quality and safety issues that may occur in animal-derived foods. Because animal production is not the only aspect of animal nutrition, it is important to consider health and disease concerns related to poultry feeding practices, environmental management, metabolic and physiological stress factors, and the selective use of feed additives and supplements on yield and product quality by improving bird immune and gut health. When it comes to antibiotic growth promoters, the narrative began in 1940 when a study by (Moore et al. 1946) found that feeding antibiotics had a growth-promoting impact. The search for an alternative to animal protein growth factor B12 sparked interest in antibiotics, which were found to be partially responsible for growth promotion in the absence of animal protein.

Several antibiotics were first used to boost growth, but by the late 1960s, the Swan Committee had reviewed their use due to the possibility of antibiotic resistance developing. They discovered that administering antibiotics to farm animals has specific dangers to the health of both humans and animals. It had caused resistance in gut bacteria of animal origin. This resistance was transferable to other microbes. Sweden was the first country in Europe to entirely prohibit the use of antibiotic growth promoters in 1985. Therefore, it has been demonstrated that the indiscriminate use of antibiotics in animal husbandry increases the threat of antimicrobial resistance in the population, leaves residues in animal products, and pollutes the environment. Now, society is more concerned with consumer confidence, food security, and information technology. Gut ecosystem modulation by pro-nutrient feed additives, perinatal nutrition, epigenetic programming, feed manufacturing technology, feed science, and computational knowledge to optimize nutrition and feeding programs will be the main factors influencing poultry nutrition over the next 25 years. The introduction of nutraceuticals as a potential method for improving poultry health and productivity is gaining attention. While nutraceuticals support immunity, disease prevention, and overall well-being, feed additives such as enzymes primarily enhance nutrient availability and digestion. The effectiveness of feed supplements varies depending on farm conditions, including factors like heat stress, microbial load, ventilation quality, and nutritional imbalances. Selecting the right combination of nutraceuticals and feed additives can help optimize poultry performance under different environmental and management conditions. Environmental factors set off a series of events in the broiler’s physiological response including the release of pro-inflammatory chemicals leading to inflammation as part of a natural stress response, which has an impact on feed intake and growth (Karl et al. 2018). It may be possible to increase the broiler chicken’s resistance to stress by adding supplements to their feed, which contain active metabolites and natural antioxidants. For this reason, the researchers are searching for additives at significantly lower costs.

Feed additives are substances, microorganisms, or preparations (other than pre-mixtures and feed materials) that are purposefully added to feed or water to carry out one or more of the following functions: they can improve the health, and physical properties of the feed to make it more suitable for processing and storage and nutritional value of the feed for better feed utilization to promote the poultry growth. By using feed additives and supplements in animal feeding, such as for broilers, one can increase daily growth rates, improve the quality of animal products, enhance feed conversion efficiency, lessen the negative environmental effects of animal waste and increase disease resistance. Nutraceuticals are found to obtain poultry products (e.g., eggs, meat) enriched with biologically active compounds like PUFA (polyunsaturated fatty acids), antioxidants, antimicrobials, vitamins, and organ-protective elements (Alagawany et al. 2019).

**2. EMERGING NUTRACEUTICALS**

Development of the modern intensive poultry farming has increased the importance of feed additives and supplements in chicken feed. The term “Nutraceutical” is a combination of two words, i.e., “Nutrition” and “Pharmaceutical.” Nutraceuticals are readily available food additives produced from natural ingredients used in both human and animal nutrition and have evolved from sources of nutrition to a vital component of support therapy for preventing and treating a wide range of diseases. They also serve an important role in improving overall health, increasing life expectancy, maintaining the structure and function of the body, and slowing the ageing process. Given the risks connected with chemical medicines, such as antibiotic resistance and drug residues in food, some countries have restricted the use of antibiotics in poultry diets. As a result, there is a high demand for organic compounds that encourage comparable growth and are favourable to poultry health. Certain nutraceuticals have demonstrated potential antioxidant, immunity-boosting, gut microbiota-modulating, and growth-enhancing effects in poultry. However, their effectiveness varies depending on the type, dosage, and physiological conditions of the birds. Some studies have reported improved production performance and meat quality with specific nutraceuticals (Alagawany et al. 2019), but further controlled research is needed.

**Emerging nutraceuticals for improved poultry production can be categorized as follows:**

1. Dietary supplements – Certain probiotics, prebiotics, and antioxidants that may enhance gut health and immune function.
2. Nutritional substances – Essential amino acids, vitamins, minerals, and fatty acids that support metabolic functions and overall growth.
3. Plant-derived compounds – Select herbs, spices, fruits, vegetables, and dietary fibers that may contribute to gut health and disease resistance, though effects vary.
4. Bioactive compounds & functional foods – Phytochemicals, bioactive peptides, and functional food components with potential immunomodulatory and antimicrobial properties.

**2.1. Phytobiotics and Phytosterol**

Phytobiotics, phytochemicals, or phytogenics are natural compounds obtained from plants. Certain phytobiotics have been reported to potentially enhance poultry feed intake, growth rate, immune response, meat quality, and gut microbiota composition (Dhama et al. 2015). However, their effectiveness is influenced by the source, concentration, and bird species, and not all phytobiotics produce the same effects. They can be easily found in fruits, vegetables, spices, essential oils, grains, and legumes at a low cost (Dhama et al. 2015). They have antibacterial, antioxidant and growth-promoting qualities. Obianwuna et al. (2024) found that incorporating phytobiotics—plant-derived feed additives—into broiler diets improved gut health and growth performance with antimicrobial and antioxidant properties, offering a sustainable alternative to antibiotics in poultry nutrition. Betaine, also known as trimethylglycine, is a naturally occurring compound found in plants and animals and is also available as an additive for animal feed. Its metabolic function as a methyl donor is widely recognized by nutritionists. As a phytobiotic, betaine can be sourced from beets, spinach, wheat, oat brans, and barley, and has been shown to improve poultry performance by alleviating heat stress, enhancing growth, nutrient digestibility, muscle yield, fat metabolism, and immunity (Salamat and Ghasemi 2016). Acting as a methyl donor, betaine, along with folic acid, compensates for the absence of labile methyl groups in poultry diets based on soybean and maize (Pillai et al. 2006). Methionine, the first limiting amino acid in poultry, is essential for protein synthesis, feather growth, and oxidative stress reduction through glutathione production. Betaine contains approximately 3.75 times as many methyl groups per molecular weight as methionine and is used in animal feed to lower costs by substituting choline chloride and methionine (Nutautaitė et al. 2020). Recent studies have further demonstrated betaine’s benefits in animal nutrition, particularly under stress conditions. As an osmolyte, betaine helps maintain water balance and cell volume, leading to improved gut morphology with taller villi and enhanced nutrient absorption. Also, betaine acts as an osmoprotectant, safeguarding cellular structures such as proteins, enzymes, and DNA from osmotic stress (Abd El-Ghany et al. 2022). This, in turn, supports enzyme secretion and overall digestive efficiency, which is particularly beneficial in poultry suffering from coccidiosis. A study by (Sharma et al. 2025) found that betaine supplementation at 0.25% in methionine-deficient diets effectively supports broiler growth performance while reducing carcass fat and breast cholesterol content. Additionally, betaine increases serum albumin levels and decreases serum uric acid and creatinine concentrations, which may contribute to lower ammonia emissions in poultry houses and reduced nitrogen release into the environment. While these findings highlight betaine’s significant role as a methyl donor and metabolic enhancer, further research is needed to confirm its long-term environmental benefits.

Phytochemicals such as soy proteins and soy isoflavones are beneficial medicinal nutrients possessing anticancer, anti-hyperglycemic, anti-hyperlipidemic, anti-hypertensive, antioxidant, neuroprotective, and anti-inflammatory properties. Phytobiotics also involve essential oils (thymol, cinnamaldehyde, terpenes, carvacrol, piperine, xanthophylls) and phenolic compounds such as flavonoids (Dhama et al. 2015). Cinnamon (*Cinnamomum verum*) has been studied for its potential effects on poultry health, including antioxidant activity, gut microbiota modulation, and antibacterial properties (O’Bryan et al. 2015; Saeed et al. 2019). Additionally, its phenolic compounds, such as cinnamaldehyde, may improve nutrient digestibility and villus morphology in the intestine (Ali et al. 2021). However, the extent of these benefits varies based on the form, dosage, and diet composition of poultry.

 Phytosterols are naturally found in vegetable oils, nuts, seeds, grains, wooden pulp, etc. Consuming phytosterols lowers blood LDL levels, increases hepatic uptake of LDL, and decreases cholesterol absorption, all of which help to prevent cardiovascular illnesses. Plant sterols derived from grains such as soy, corn, and sunflower have been investigated for their potential role in modulating cholesterol metabolism and muscle development in poultry. Some studies suggest positive effects on chick growth and embryo development (Poli and Visioli 2019), but further research is needed to establish optimal dietary inclusion levels.

**2.2. Spices and Herbs**

Certain Ayurvedic herbal remedies have been investigated for their potential effects in poultry production. While some studies suggest that specific herbs and spices may support gut health, immunity, and disease resistance, their effectiveness varies depending on dosage, bioavailability, and poultry species. Certain herbs and plant oils have also been studied for their potential benefits in poultry nutrition. Some oils contain bioactive compounds with anti-inflammatory, antioxidant, and antibacterial properties (Reda et al. 2020). However, their effects depend on source, concentration, and bird health status, and not all plant-derived oils provide the same benefits. Among the herbs and spices evaluated as potential AGP (antibiotic growth promoter) alternatives in poultry nutrition are cinnamon, garlic, oregano, rosemary, ginger, coriander, black cumin, and turmeric.

Garlic (*Allium sativum*) has been studied for its potential anti-hyperlipidemic and antihypertensive effects in poultry nutrition. Some findings suggest that it may help reduce endogenous cholesterol synthesis and facilitate cholesterol excretion, thereby contributing to a more favorable HDL/LDL ratio (Chakraborty and Roy 2021). Thio-sulfinates, a class of organo-sulfur compounds, have been identified as key bioactive components in garlic, with allicin accounting for approximately 70% of total thio-sulfinates. Allicin has been associated with antimicrobial and antioxidant activities, which may contribute to gut microbiota modulation and overall health benefits (Lawson et al. 2001).

Some studies suggest that garlic supplementation could play a role in lipid metabolism regulation and immune modulation in livestock; however, its effects depend on dosage, formulation, and animal species (Lewis and Lewis 2003). While garlic contains bioactive compounds with antibacterial, antioxidant, and potential immunomodulatory properties, further controlled trials are needed to determine its optimal inclusion levels and long-term efficacy in poultry diets.

Cinnamon (*Cinnamomum verum*) has been investigated for its potential to enhance poultry meat sensory attributes. Studies indicate that a 0.5% inclusion of cinnamon powder may improve flavor, texture, and feed efficiency, potentially serving as a phytobiotic alternative to AGPs in broiler production (Singh et al. 2014). Additionally, cinnamon supplementation has been associated with reduced Eimeria oocyst shedding, suggesting a possible role in coccidiosis management in poultry (Youn et al. 2008). However, the extent of these benefits varies depending on dosage, bird species, and dietary composition.

Curcumin (diferuloylmethane), a polyphenol in turmeric (*Curcuma longa*), has been studied for its anti-inflammatory, anticarcinogenic, and antioxidant properties. Some research suggests that turmeric rhizomes, beetroots, spinach leaves, and cucumber fruits contain bioactive compounds with potential anti-tumor activity. In a study conducted by Hussein (2013), supplementation of 7 g/kg turmeric powder in broiler diets resulted in improved body weight gain, liver function, gizzard performance, and periventriculus indices. Additionally, Kanani et al. (2016) concluded that dietary supplementation with cinnamon and turmeric, either alone (0.25%) or together (0.5%), may help improve broiler performance under heat stress conditions by reducing lipid peroxidation.

Feeding water fern (*Azolla pinnata*) to broilers at a 2.5% dietary inclusion level has been associated with increased breast muscle yield, improved gizzard weight, and reduced meat pH. The addition of direct-fed microbials (DFM) to an Azolla-based diet has further enhanced these effects (Shambhvi et al. 2020). The plant compounds, along with their source and therapeutic use, have been mentioned in Table 1. The growth performance of feed additives according to the literature search has been mentioned in Table 2.

**2.3. Fruits, Vegetables and Dietary Fibres**

Dietary fibre is a natural component of plants that consists of non-starch polysaccharides (NSP), oligosaccharides, and lignin that escape digestion and enzymatic hydrolysis. Certain insoluble dietary fibers have been studied for their potential role in poultry nutrition. Some findings suggest that fiber sources such as rice bran and corn bran may help modulate intestinal morphology and support nutrient absorption (Sittiya et al. 2020). However, the effects of dietary fiber vary depending on fiber type, concentration, and the bird’s physiological status Fermentation of fibres in the gastrointestinal tract leads to the formation of SCFAs, such as butyric acid that acts as an energy source of the intestinal epithelium, and antimicrobial and anti-inflammatory compounds (Namkung et al. 2011). Buckwheat, fava beans, and hemp flour enriched with anthocyanins may have applications in the prevention and treatment of chronic diseases, in addition to displaying the use of sustainable and environmentally friendly practices in feed units. Rice bran has zeaxanthin and lutein, which improve vision and prevent cataracts. Corn is a great supplier of folate and fibre. Broiler chicks were fed with basal feed supplemented with vegetable waste from potatoes, spinach, and cauliflower. Incorporating 25% vegetable waste in broiler diets has been associated with potential improvements in body weight, blood profile, and carcass yield (Nisar et al. 2022). However, effects vary depending on the composition of vegetable waste, nutrient balance, and feeding conditions. Better meat lipid oxidation status and better meat mineral content was observed when birds were fed vegetable waste (VW) at 25, 50, 75, and 100% of the diets, respectively, compared with 100% commercial feed, and results indicated that VW may replace up to 75% of commercial broiler feeds with beneficial effects (Raza et al. 2019). Tangerines, grapefruits, lemons, and oranges are among the citrus fruits that contain the weak organic acid known as citric acid (2-hydroxy-1,2,3-propane-tricarboxylic acid). The results of a 35-day study evaluating Citric Acid as a feed additive in poultry broiler feed with lower mineral content of calcium (Ca) and Total phosphorus (TP) showed activation of homeostatic mechanisms of Ca and phosphorus digestion and absorption, improved FCR, improved carcass characteristics, and higher growth rate, as well as better nutrient utilization with a positive impact on dressing percentage (Katoch et al. 2023). (Chauhan et al. 2024) concluded that Supplementing Him-Samridhi (HS) layer birds with Developed Supplemented Feed (DSF)—a mix of Urtica diocia (Bichubooti), Nasturtium officinalis (Choograss), Rumex hastatus (Malori leaves), and vegetable waste—at 20 grams per bird per day, significantly improved hen-day egg production (HDEP) across all age groups (23, 40, 52, and 64 weeks). DSF also enhanced egg quality traits and increased essential mineral content (Se, Ca, Fe, Mn, K, Cu, Mg), indicating its potential as a sustainable and cost-effective dietary supplement for improving egg productivity and nutritional value in poultry. Further studies are needed to explore its long-term impacts on poultry health and production.

**2.4. Probiotics and Prebiotics**

Incorporating feed additives, such as probiotics, prebiotics, phytobiotics, and enzymes, into poultry diets may improve digestive efficiency and overall health. While feed additives primarily enhance nutrient utilization and digestion, some—like probiotics and phytobiotics—also exhibit nutraceutical properties by promoting gut microbiota balance and immune function. Probiotics and prebiotics support gut health by modulating microbiota, enhancing nutrient absorption, and stimulating the production of beneficial short-chain fatty acids (SCFAs), rather than directly containing bioactive compounds.

Probiotics, in particular, may help regulate feed intake, enhance weight gain, and improve feed conversion ratios by fostering beneficial microbial populations and competitively excluding harmful bacteria. Additionally, these supplements aid digestion, reduce digestive disturbances, strengthen immunity through cytokine stimulation, lower ammonia synthesis, decrease mortality rates, and contribute to cost-effective poultry production (Al-Khalaifah 2018).

The term "probiotic" was coined by Parker in 1974, who defined it as live microorganisms and substances that contribute to intestinal microbial balance. Direct-fed microbials (DFM) are a category of live microbial feed supplements that enhance gut microbiota and improve overall digestive health. DFM provides two key benefits:

* Maintaining a stable and beneficial gut microflora by preventing the proliferation of harmful microorganisms.
* Enhancing intestinal health by increasing enzyme activity and nutrient bioavailability.

A systematic review by (Jha et al.2020) analyzed various studies and found that supplementing poultry diets with Lactobacillus-based direct-fed microbials (DFMs) can enhance nutrient retention, including nitrogen (N), calcium (Ca), and phosphorus (P). While probiotic supplementation improved nutrient utilization, growth performance, and gut health in poultry. The review highlighted that Lactobacillus-based DFMs positively influence the gut microbiota, leading to better nutrient absorption and retention.

According to the United Nations and World Health Organization (WHO) expert panel, probiotics are live microorganisms that, when administered in adequate amounts, provide health benefits to the host. Commonly used probiotic species in poultry include Gram-positive bacteria such as *Enterococcus, Lactobacillus, Pediococcus*, and *Bacillus*, as well as yeast strains like *Saccharomyces cerevisiae*. A probiotic must meet key criteria, including:

* Non-pathogenic and non-toxic
* Providing measurable health benefits
* Surviving in the gastrointestinal tract under acidic conditions
* Being classified as "Generally Regarded As Safe (GRAS)"

Probiotics enhance poultry immunity through two mechanisms:

1. Competitive exclusion: This occurs when beneficial bacteria colonize the gut, preventing pathogenic bacteria from establishing themselves. Probiotics achieve this by producing inhibitory compounds such as bacteriocins, organic acids, and hydrogen peroxide, which suppress harmful bacteria. Additionally, they compete for binding sites and nutrients, effectively reducing pathogen adhesion and colonization. Moreover, probiotics stimulate the host’s immune system, enhancing both innate and adaptive immune responses (Halder et al. 2024).
2. Immune modulation: Probiotics help maintain a balanced intestinal microflora through competitive exclusion and antagonism. They also alter metabolism by increasing digestive enzyme activity and stimulating the immune system, thereby improving feed intake and digestion (Kabir, 2009).

Apata (2008) found that *Lactobacillus bulgaricus* supplementation improved the humoral immune response in broilers, while Kannan et al. (2005) reported that *L. sporogenes* enhanced immunity against Newcastle disease (Ranikhet disease). Another proposed mechanism is competitive exclusion, which prevents opportunistic pathogen colonization by probiotic bacteria. Ramesh et al. (2000) demonstrated that birds supplemented with *L. acidophilus* had reduced surface pH levels in the duodenum, jejunum, ileum, and cecum, creating an unfavorable environment for harmful bacteria. Probiotics also promote gut health by producing metabolic end products such as lactate, succinate, SCFAs (acetate, propionate, butyrate), and bacterial biomass, which enhance nutrient absorption and contribute to overall growth. Short-chain fatty acids (SCFAs), particularly butyrate, serve as an energy source for intestinal epithelial cells and may help reduce intestinal inflammation. Additionally, probiotics improve bone mineral density and bioavailability of essential minerals (Mutuş et al. 2006). In a study by Awad et al. (2009), probiotic supplementation in poultry diets increased crypt cell proliferation in the small intestine and significantly increased ileal villus height, indicating improved nutrient absorption. Katoch et al. (2017) isolated *Lactobacillus casei* from leopard (*Panthera leo*) feces and administered it to Vancobb commercial broilers for six weeks, reporting improved overall growth performance at 6.8 × 10⁸ CFU/mL. Similarly, Pietras et al. (2001) found that supplementing poultry diets with *Lactobacillus rhamnosus* improved protein content in meat while reducing crude fat and cholesterol levels.

Prebiotics are non-digestible fibers that are not hydrolyzed or absorbed in the gastrointestinal tract but serve as a substrate for probiotics, promoting the growth of beneficial gut microbiota. The most commonly used prebiotics in poultry nutrition include fructooligosaccharides (FOS), which enhance gut health by stimulating the production of beneficial metabolites such as SCFAs. Other prebiotics used in poultry diets include:

* Fruits and legumes (e.g., bananas, apples, soybeans)
* Cereals and whole grains (e.g., oats, barley, wheat bran)
* Oligosaccharides (e.g., galacto-oligosaccharides, xylo-oligosaccharides)
* Lactulose, isomalto-oligosaccharides, and pyrodextrins

By selectively promoting the growth of beneficial microbes, prebiotics enhance gut health, improve digestion, boost immunity, and increase nutrient utilization in poultry. A study conducted by (Hashem et al. 2022) concluded that Dietary supplementation with probiotics (Lactobacillus plantarum) and prebiotics (amylase enzyme) in broiler chicks improved growth performance, enhanced immune response, increased antioxidant enzyme activity, and promoted better liver and kidney function. Additionally, these supplements reduced DNA damage and histopathological changes in vital organs, suggesting their potential as effective prophylactic agents to support poultry health and protect against Escherichia coli infections.

**2.5. Antioxidants**

Reactive oxygen species (ROS) are free radicals derived from nitrogen and oxygen. Antioxidants are necessary to stop lipid oxidation, which lowers the quality and safety of feedstuffs. Numerous antioxidants are derived from nutrients such as carotenoids, ascorbic acid (vitamin C), tocopherols and tocotrienols (vitamin E), and low molecular weight substances like glutathione and lipoic acid. Free radical quenching processes are catalyzed by antioxidant enzymes such as glutathione reductase, superoxide dismutase, and glutathione peroxidase. On the other hand, oxidative reactions are catalyzed by metal-binding proteins such as ceruloplasmin, albumin, ferritin, and lactoferrin. There are other endogenous antioxidant agents, including ubiquinone (coenzyme Q10), bilirubin, NADPH, and NADH, uric acid, thiols (glutathione, N-acetyl cysteine, and lipoic acid), enzymes (copper/zinc and manganese-dependent superoxide, selenium-dependent glutathione peroxidase, and iron-dependent catalase), and dietary antioxidants (vitamin C, vitamin E, beta carotene) and oxycarotenoids (lutein and lycopene). Lycopene, a carotenoid found in tomatoes, carrots, and guava, acts as a potent antioxidant in poultry. It enhances antioxidant enzyme activity (SOD, GSH-Px, CAT), increases total antioxidant capacity (T-AOC), and reduces malondialdehyde (MDA) levels. Lycopene also helps alleviate heat stress, supports immune function, and protects against oxidative damage caused by toxins, improving overall poultry health and performance (Hidayat et al. 2023) Plant polyphenols (flavan-3-ol), flavonols, tannins, anthocyanins, and derivatives of phenolic acid proanthocyanidins (Pas), which are composed of procyanidin and esterified gallic acid, are among the physiologically active phenolic compounds found in grape seed extract. These compounds prevent lipid oxidation in poultry during gastric digestion (Bonilla and Sobral 2016). In a study conducted (Xiao et al.2024) by a novel antioxidant compound (AC) containing 18% butylated hydroxytoluene (BHT), 3% citric acid, and 1% tertiary butylhydroquinone (TBHQ) has shown promising benefits in broiler diets. Compared to ethoxyquin (EQ), AC improved feed oxidative stability by reducing acid value, peroxide value, and malondialdehyde content in stored feed. It enhanced antioxidant capacity by increasing liver total antioxidant capacity (T-AOC), superoxide dismutase (SOD), and intestinal catalase and glutathione peroxidase (GPx7) levels. AC also improved intestinal morphology, reduced barrier permeability, and promoted the expression of tight junction proteins, strengthening gut integrity. Furthermore, it enhanced immune regulation and increased beneficial gut microbiota like Lactobacillus while reducing harmful bacteria.

**2.6. Amino acids**

Structural and functional units of protein are called amino acids, divided into two nutritional categories: non-essential (produced by the body) and essential (unable to be produced quickly enough to satisfy the body's metabolic needs). Protein’s structural and functional building blocks, amino acids are divided into two nutritional categories: non-essential (produced by the body) and essential (unable to be produced quickly enough to satisfy the body’s metabolic needs). Amino acids are essential for many bodily functions. The poultry birds’ nutritional requirements must be supplemented with ten essential amino acids: lysine, methionine, threonine, tryptophan, arginine, leucine, isoleucine, phenylalanine, histidine, and valine. Threonine is the third limiting amino acid among these necessary amino acids, with methionine and lysine being the first and second limiting amino acids for broilers, respectively. For juvenile birds, glycine is an essential amino acid. Tyrosine and Cysteine are semi-essential amino acids, as they can be synthesized from phenylalanine and methionine, respectively.

Nutritional supplements with amino acid chelated trace minerals reduced the levels of pro-inflammatory cytokine gene expression and circulatory and intestinal heat shock protein 70 (HSP70) while improving gut health by lessening the effects of heat stress, according to research on day-old Cobb-500 male broilers (Baxter et al. 2020). When amino acids are supplemented, total short-chain fatty acids and caecal butyric acid are produced, which aids in growth, development, feed conversion efficiency, and immunity (Hilliar et al. 2020). Protein synthesis, DNA methylation, ROS elimination, and the synthesis of glutathione (GSH), a tripeptide that lowers ROS and protects cells from oxidative stress are all processes in that methionine is involved. The addition of dietary methionine to the feed increased the growth performance of 42-day-old broiler chickens (Wen et al. 2017). Threonine’s importance for gut health is demonstrated by the fact that its presence in the lumen speeds up the synthesis of mucosal protein and mucin (Nichols and Bertolo 2008). Threonine is a precursor to several compounds, including glutathione, which is vital to the body’s antioxidant defence mechanism. The greatest post-hatch relative development occurs in the GIT, particularly in the small intestine of chicken. The ability of newly hatched chicks to use nutrients, absorb food, generate several immunoglobulins, and grow may therefore be negatively impacted by early feed shortage, which may lead to decreased intestinal enterocyte length and villus surface area. (Uni and Ferket 2003). Early nutrition programming has been utilized to maintain homeostasis and a high body temperature during the first post-embryonic days, as well as to regulate the early growth and development of the GIT during the perinatal period from the late-term embryo to a few days after hatching. Both in-ovo and post-hatch feeding techniques are used. For instance, growth performance is improved by supplementing with L-lysine, threonine, L-histidine, and L-arginine, which are amino acids. Additionally, in ovo injection of sulfur-containing amino acids (cysteine and methionine) into heat-stressed embryonated eggs has been shown to lower the lipid profile of newly hatched broiler chicks and improve antioxidant indices and gene expression (Yadav and Jha 2019).

**2.7. Functional food**

Functional foods are fortified food with bioactive compounds that are designed or modified using technology or animal nutrition to offer potential health benefits, disease prevention, and enhancing immunity beyond basic nutrition. Mushrooms are being investigated as a conceivable source of functional food ingredients, with some species displaying positive results in terms of the prevention of diseases. Nutraceutical feed additives such as microalgae contain bioactive compounds like carotenoids, phycocyanin, and polyunsaturated fatty acids, which provide anti-inflammatory, antioxidant, and immune-boosting benefits in poultry. (Zanella and Vianello 2023). Microalgae (*Arthrospira platensis, Chlorella vulgaris, Staurosira sp., Schizochytrium sp.*) have proven to improve poultry meat characteristics, PUFA-ω3, EPA, DHA, and antibiotic activity. Spirulina (Arthrospira platensis) has the potential to be a useful component in the diet of broiler chickens. It can raise PUFA levels in thigh meat by 5 g/kg (Bonos et al. 2016).

* 1. **Fatty acids**

Fatty acids play a crucial role in poultry nutrition, contributing to overall health, productivity, and the quality of poultry products. Among the essential polyunsaturated fatty acids (PUFAs) found in cell membranes are omega-3 fatty acids—docosahexaenoic acid (DHA), eicosapentaenoic acid (EPA), and α-linolenic acid (ALA)—and omega-6 fatty acids, including arachidonic acid and linolenic acid. Omega-3 fatty acids are primarily sourced from fish oils, plants, and nuts, while omega-6 fatty acids can be found in rapeseed, soybean, and sunflower oils. Animal fat and olive oil contain omega-9 fatty acids, which are non-essential as they can be synthesized by the body. Since eggs are not naturally rich in ω-3 PUFAs, supplementation in poultry diets is necessary to obtain ω-3-enriched eggs.

Fatty acids play a significant role in preventing cardiovascular diseases. For instance, omega-3 fatty acids lower low-density lipoprotein (LDL) cholesterol while increasing high-density lipoprotein (HDL) cholesterol levels, reducing the risk of cardiac arrhythmias (Oken et al., 2004). Rice bran, which is rich in omega-9 and folic acid, also contributes to lowering LDL levels and increasing HDL. In addition to cardiovascular benefits, short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate—produced by commensal bacteria—exhibit strong anti-inflammatory effects by protecting the intestinal lining and reducing intestinal damage (Ibrahim et al., 2018). PUFAs also play a critical role in improving mineral metabolism, particularly in enhancing the absorption of essential minerals like calcium, zinc, and magnesium, which are vital for bone development. Furthermore, these fatty acids improve immune system function in broiler chickens, enhancing their resistance to various diseases. The positive effects extend to improving the quality of poultry meat and eggs by enriching them with essential fatty acids, thereby increasing their nutritional value.

Recent research by Attia et al. (2022) has demonstrated the impact of varying the ω-6/ω-3 PUFA ratio in poultry diets on performance and product quality. The study found that a ω-6/ω-3 PUFA ratio of 9.3:1 improved laying performance, egg production, and feed efficiency. In contrast, a lower ratio of 5.5:1 enhanced egg quality by increasing ω-3 deposition in the yolk and boosting the birds' immune responses. However, reducing the ω-6/ω-3 ratio slightly decreased eggshell thickness. The intermediate ω-6/ω-3 ratio of 9.3:1 appears to strike a balance between improved laying performance and product quality, while the lower ratio of 5.5:1 is more effective for enhancing the nutritional profile of eggs and strengthening immune function. The supplementation of ω-3 PUFAs in poultry diets is essential to produce enriched eggs that offer significant health benefits to consumers. In addition to improving the birds' immune response and mineral metabolism, PUFAs contribute to reducing inflammation and enhancing the antioxidant capacity of poultry. These benefits underscore the importance of optimizing the ω-6/ω-3 PUFA ratio in poultry nutrition to promote bird health, improve production efficiency, and deliver high-quality poultry products.

**2.9. Bioactive Peptides**

Bioactive peptides, comprising 3 to 50 amino acids, are derived from hydrolyzed animal byproducts such as ruminant and pig leather, chicken feet, skin, intestines, liver, trachea, bones, blood, plasma, eggs and milk (casein and whey). They can also be separated from a wide variety of dietary proteins from plants. These peptides exhibit antioxidant, antihypertensive, antihyperglycemic, and anti-inflammatory properties, enhancing nutrient bioavailability and sensory attributes (Vasconcellos et al.2024). The most common sources of animal protein are meat proteins. Soy, oats, pulses (chickpeas, beans, peas, and lentils), wheat, canola, flaxseed, and hemp seed are common plant sources for bioactive peptides. Casein and whey protein derived from milk contain natural angiotensin-converting enzyme inhibitors, and they also exert antihypertensive effects. Supplementation with carotenoids, bioactive peptides, botanical extracts, bioactive polysaccharides, etc., in various human trials has evidenced protection against UV radiation and fewer signs of aging (Pérez-Sánchez et al. 2018). Bioactive peptides derived from fish waste act as nutraceuticals, providing antioxidant benefits, delaying lipid oxidation in broiler breast meat, and extending meat shelf life, as demonstrated in a study by (Aslam et al. 2020). Sesame meal bioactive peptide was found to reduce *E. coli* in the gut, and improve productive performance, gut microbial population, and intestinal morphology in broiler chickens.

**3. CONCLUSION**

Poultry production continues to expand rapidly, driven by the global demand for affordable, high-quality protein. However, the industry faces increasing pressure to balance productivity with consumer concerns over food safety, antibiotic resistance, and sustainability. The shift toward antibiotic-free poultry farming requires innovative nutritional strategies that maintain bird health, performance, and meat quality without compromising efficiency. While nutraceuticals present a potential alternative to conventional antibiotic growth promoters, their effective application remains a challenge due to variability in efficacy, optimal dosage requirements, and species-specific responses. Ensuring scientifically validated, standardized, and cost-effective nutraceutical solutions is essential for their widespread adoption in commercial poultry production. Moving forward, collaborative efforts between researchers, industry stakeholders, and policymakers are necessary to optimize nutraceutical formulations, assess long-term impacts, and develop regulatory guidelines. A strategic, research-driven approach will be key to integrating nutraceuticals into poultry farming, enhancing bird health, improving production efficiency, and meeting the growing demand for antibiotic-free poultry products sustainably.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**Conflict of interest**

All authors declare no other competing interests.

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**Availability of data and material**

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**Code availability**

No custom code pursue used in the preparation of this review article

**References**

Abd El-Ghany, Wafaa A, and Daryoush Babazadeh.2022. “Betaine: A Potential Nutritional Metabolite in the Poultry Industry.” *Animals* : an open access journal from MDPI vol. 12,19 2624.doi:10.3390/ani12192624

Ahmed El-Hady AM, Elghalid OA, Elnaggar AS, and Abd El-khalek E .2022.”Growth performance and physiological status evaluation of Spirulina platensis algae supplementation in broiler chicken diet”. *Livestock Science* :263:105009. doi: 10.1016/j.livsci.2022.105009.

Akhavan-Salamat H and Ghasemi HA .2016.” Alleviation of chronic heat stress in broilers by dietary supplementation of betaine and turmeric rhizome powder: dynamics of performance, leukocyte profile, humoral immunity, and antioxidant status.” *Tropical Animal Health Production*. 48:181-188. doi: 10.1007/s11250-015-0941-1.

Alagawany M, Elnesr SS, Farag MR, Abd El-Hack ME, Khafaga AF, Taha AE, Tiwari R, Yatoo MI, Bhatt P, Khurana SK, and Dhama K .2019.” Omega-3 and omega-6 fatty acids in poultry nutrition: effect on production performance and health”. *Journal Animal* (8):573. doi: 10.3390/ani9080573.

Ali A, Ponnampalam EN, Pushpakumara G, Cottrell JJ, Suleria HA, and Dunshea FR .2021.” Cinnamon: A natural feed additive for poultry health and production”—A review. *Journal Animal* 11(7):2026. doi: 10.3390/ani11072021.

Al-Khalaifah HS .2018.” Benefits of probiotics and/or prebiotics for antibiotic-reduced poultry”. *Poultry Science*: 97(11):3807-3815. doi: 10.3382/ps/pey160.

Apata DF .2008. “Growth performance, nutrient digestibility and immune response of broiler chicks fed diets supplemented with a culture of *Lactobacillus bulgaricus*.” *Journal of the Science and Food and Agriculture* :88(7):1253-1258. doi: 10.1002/jsfa.3214.

Aslam S, Shukat R, Khan MI, and Shahid M .2020. “Effect of dietary supplementation of bioactive peptides on antioxidant potential of broiler breast meat and physicochemical characteristics of nuggets”. *Food Science and Animal Resources*: 40(1):55-73. doi: 10.5851/kosfa.2019.e82.

Attia, Youssef A., Mohammed A. Al-Harthi, Ahmed A. Al-Sagan, Adel D. Alqurashi, Mohamed A. Korish, Nisreen M. Abdulsalam, Marai J. Olal, and Fulvia Bovera. 2022. "Dietary Supplementation with Different ω-6 to ω-3 Fatty Acid Ratios Affects the Sustainability of Performance, Egg Quality, Fatty Acid Profile, Immunity and Egg Health Indices of Laying Hens" *Agriculture* 12, no. 10: 1712. https://doi.org/10.3390/agriculture12101712

Awad WA, Ghareeb K, Abdel-Raheem S and Böhm J .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. doi: 10.3382/ps.2008-00244.

Baxter MF, Greene ES, Kidd MT, Tellez-Isaias G, Orlowski S, and Dridi S .2020. “Water amino acid-chelated trace mineral supplementation decreases circulating and intestinal HSP70 and pro inflammatory cytokine gene expression in heat-stressed broiler chickens”. *Journal of Animal Science:* 8(3). doi: [10.1093/jas/skaa049](https://doi.org/10.1093/jas/skaa049).

Bonilla J, and Sobral PJ .2016. “Investigation of the physicochemical, antimicrobial and antioxidant properties of gelatin-chitosan edible film mixed with plant ethanolic extracts.” *Food Bioscience* :16:17-25. doi: [10.1016/j.fbio.2016.07.003](https://doi.org/10.1016/j.fbio.2016.07.003).

Bonos E, Kasapidou E, Kargopoulos A, Karampampas A, Nikolakakis I, Christaki E and Florou-Paneri P.2016. “Spirulina as a functional ingredient in broiler chicken diets.” *South Africa Journal of Animal Science.* :94-102. doi: [10520/EJC187296](https://hdl.handle.net/10520/EJC187296).

Chakraborty R, and Roy S.2021. “Angiotensin-converting enzyme inhibitors from plants: A review of their diversity, modes of action, prospects, and concerns in the management of diabetes-centric complications.” *Journal of Integrated Medicine* .19(6):478-92. doi:10.1016/j.joim.2021.09.006

Chauhan, Sunidhi & Katoch, Shivani & Sankhyan, Varun & Dinesh, Krishnender & Sharma, Arun & Rani, Daisy. 2024. “Biological evaluation of Developed Supplement Feed (DSF) for egg quality parameters in LIT (Himsamridhi) birds”. *The Pharma Innovation*. 13. 10.22271/tpi.2024.v13.i2c.25372.

Diaz Carrasco JM, Casanova NA, and Fernández Miyakawa ME .2019.”Microbiota, gut health and chicken productivity: what is the connection? Microorganisms.” 7(10):374. doi: 10.3390/microorganisms7100374.

Fitasari EK, and Mushollaeni W.2020. “The Potential of Vegetable Waste-Based Pellets on Broiler Production Performanceand Nutrient Digestibility”. *IOSR Journal of Agriculture and Veterinary Science*. 13(11):18-24.doi: 10.9790/2380-1311011824.

Giannenas I, Sidiropoulou E, Bonos E, Christaki E,and Florou-Paneri P .2020. Chapter-“The history of herbs, medicinal and aromatic plants, and their extracts: Past, current situation and future perspectives. Feed additives.” 1-18. doi: 10.1016/B978-0-12-814700-9.00001-7.

Halder, N., Sunder, J., De kumar, A., Bhattacharya,D., Joardar,S.N. 2024. “Probiotics in poultry: a comprehensive review”. *The Journal of Basic and Applied Zoology.* 85, 23.https://doi.org/10.1186/s41936-024-00379-5.

Hashem, M. A., Hassan, A. E. A., Abou-Elnaga, H. M. M., Abdo, W., Dahran, N., Alghamdi, A. H., & Elmahallawy, E. K. (2022). Modulatory effect of dietary probiotic and prebiotic supplementation on growth, immuno-biochemical alterations, DNA damage, and pathological changes in E. coli-infected broiler chicks. Frontiers in veterinary science, 9, 964738. https://doi.org/10.3389/fvets.2022.964738

Hidayat, Dalila Fadhila, Mahendra, Mohamad Yusril Nur, Kamaludeen, Juriah, Pertiwi, Herinda, Lycopene in Feed as Antioxidant and Immuno-Modulator Improves Broiler Chicken’s Performance under Heat-Stress Conditions, Veterinary Medicine International, 2023, 5418081, 7 pages, 2023. https://doi.org/10.1155/2023/5418081

Hilliar M, Keerqin C, Girish CK, Barekatain R, Wu SB, and Swick RA .2020.” Reducing protein and supplementing crystalline amino acids, to alter dietary amino acid profiles in birds challenged for subclinical necrotic enteritis”. *Poultry Science :*99(4):2048-2060. doi: 10.1016/j.psj.2019.11.042.

Hussein SN .2013.” Effect of turmeric (*Curcuma longa*) powder on growth performance, carcass traits, meat quality, and serum biochemical parameters in broilers”. *Journal of Advanced Biomedical & Pathobiology Research .*3(2):25-32.

Ibrahim D, El-Sayed R, Khater SI, Said EN, and El-Mandrawy SA.2018.” Changing dietary n-6: n-3 ratio using different oil sources affects performance, behavior, cytokines mRNA expression and meat fatty acid profile of broiler chickens”. *Animal Nutrition.* 4(1):44-51. doi: 10.1016/j.aninu.2017.08.003.

Inoue M, Hayashi S, and Craker LE.2019.” Role of medicinal and aromatic plants: Past, present, and future”. Pharmacognosy-medicinal plants. 13:1. doi: 10.5772/intechopen\_82497.

Jha, Rajesh, Razib Das, Sophia Oak, and Pravin Mishra. 2020. "Probiotics (Direct-Fed Microbials) in Poultry Nutrition and Their Effects on Nutrient Utilization, Growth and Laying Performance, and Gut Health: A Systematic Review" Animals 10, no. 10: 1863. https://doi.org/10.3390/ani10101863.

Kabir, S. M. Lutful. 2009. "The Role of Probiotics in the Poultry Industry" International Journal of Molecular Sciences 10, no. 8: 3531-3546. https://doi.org/10.3390/ijms10083531

Kanani PB, Daneshyar M, and Najafi R .2016. “Effects of cinnamon (*Cinnamomum zeylanicum*) and turmeric (*Curcuma longa*) powders on performance, enzyme activity, and blood parameters of broiler chickens under heat stress”. *Poultry Science Journal*: 4(1),47-53.

Kannan M, Karunakaran R, Balakrishnan V, and Prabhakar TG.2005.”Influence of prebiotics supplementation on lipid profile of broilers.” *International Journal of Poultry Science*: 4(12):994-997. doi: 10.3923/ijps.2005.994.997.

Karl JP, Hatch AM, Arcidiacono SM, Pearce SC, Pantoja-Feliciano IG, and Soares JW .2018. “Effects of psychological, environmental and physical stressors on the gut microbiota”. *Frontiers in Microbiology.* 9: 372026. doi: 10.3389/fmicb.2018.02013.

Katoch S, Sharma S, Sankhyan V, Wadhwa D, Sharma A, and Kumar S .2023. “Growth studies in commercial broiler birds offered citric acid in formulated feed with low mineral density”. *Tropical Animal Health and Production.* 55(1):33. doi: 10.1007/s11250-022-03443-w.

Katoch S, Thakur S, and Rajput R .2017. “Effect of Probiotic Supplementation in broiler birds offered feed formulated with lower protein densities.” *International Journal of Livestock Research*. 7(2): 1-3. doi: 10.5455/ijlr.20170205013927.

Kuldeep Dhama KD, Latheef SK, Saminathan Mani SM, Samad HA, Karthik K, Ruchi Tiwari RT, Khan RU, Alagawany M, Farag MR, Alam GM, and Laudadio V .2015. “Multiple beneficial applications and modes of action of herbs in poultry health and production-a review.” *International Journal of Pharmacology.* 11: 152-176. doi: 10.3923/ijp.2015.152.176.

Lawson LD, Wang ZJ, and Papadimitriou D .2001. “Allicin release under simulated gastrointestinal conditions from garlic powder tablets employed in clinical trials on serum cholesterol”. *Planta Medica*. 67(1):13-18. doi: 10.1055/s-2001-10624.

Lewis WH, and Elvin-Lewis MP .2003. “Medical botany: plants affecting human health”. John Wiley & Sons: 70.

Moore PR, Evenson A, Luckey TD, McCoy E, Elvehjem C, and Hart EB .1946.”Use of sulfasuxidine, streptothricin, and streptomycin in nutritional studies with the chick". *Journal of Biological Chemistry.* 165:437–41.

Mutuş R, Kocabağli N, Alp M, Acar NÜ, Eren MU, and Gezen ŞŞ .2006.” The effect of dietary probiotic supplementation on tibial bone characteristics and strength in broilers.” *Poultry Science.* 85(9):1621-1625. doi: 10.1093/ps/85.9.1621.

Namkung H, Yu H, Gong J,and Leeson S.2011.” Antimicrobial activity of butyrate glycerides toward *Salmonella* Typhimurium and *Clostridium perfringens*.” *Poultry Science.* 90(10):2217-2222. doi: 10.3382/ps.2011-01498.

Nichols NL,and Bertolo RF. 2008.”Luminal Threonine Concentration Acutely Affects Intestinal Mucosal Protein and Mucin Synthesis in Piglets.” *Journal of Nutrition*. 138(7):1298-303. doi: 10.1093/jn/138.7.1298.

Nisar MS, Zahra A, Iqbal MF, Bashir MA, Yasin R, Samiullah K, Aziz I, Saeed S, Alasmari A, Elsaid FG, and Shati AA.2022.” Effect of Vegetable Waste on Growth Performance and Hematology of Broiler Chicks”. *BioMed Research International*. 2022(1):4855584. doi: 10.1155/2022/4855584.

Nutautaitė M, Alijošius S, Bliznikas S, Šašytė V, Vilienė V, Pockevičius A, Racevičiūtė-Stupelienė A .2020.” Effect of betaine, a methyl group donor, on broiler chicken growth performance, breast muscle quality characteristics, oxidative status and amino acid content”. *Italian Journal of Animal Science.* 19(1):621-629. doi:10.1080/1828051X.2020.1773949.

O’Bryan CA, Pendleton SJ, Crandall PG, and Ricke SC.2015.” Potential of plant essential oils and their components in animal agriculture–in vitro studies on antibacterial mode of action.” *Frontiers in  Veterinary Science.* 2:35. doi: 10.3389/fvets.2015.00035.

Obianwuna, U.E., Chang, X., Oleforuh-Okoleh, V.U., Onu,P.N., Zhang,H, Qiu,K, Wu,S. 2024.”Phytobiotics in poultry: revolutionizing broiler chicken nutrition with plant-derived gut health enhancers”. *Journal of Animal Science and Biotechnology.15*, 169. https://doi.org/10.1186/s40104-024-01101-9

Oken E, Kleinman KP, Olsen SF, Rich-Edwards JW, and Gillman MW .2004.”Associations of seafood and elongated n-3 fatty acid intake with fetal growth and length of gestation: results from a US pregnancy cohort.” *American Journal of Epidemiology*. 160(8):774-83. doi: 10.1093/aje/kwh282.

Park JH, and Kim IH .2019.” Effects of dietary Achyranthes japonica extract supplementation on the growth performance, total tract digestibility, cecal microflora, excreta noxious gas emission, and meat quality of broiler chickens.” *Poultry Science.* 99(1):463-470. doi: 10.3382/ps/pez533.

Pérez-Sánchez A, Barrajón-Catalán E, Herranz-López M, and Micol V .2018. “Nutraceuticals for skin care: A comprehensive review of human clinical studies”. *Nutrients* 10(4):403. doi: 10.3390/nu10040403.

Pietras M .2001.”The effect of probiotics on selected blood and meat parameters of broiler chickens”*. Journal of Animal Feed Science*. 10:297-302. doi: 10.22358/jafs/70112/2001.

Pillai PB, Fanatico AC, Beers KW, Blair ME,and Emmert JL.2006. “Homocysteine remethylation in young broilers fed varying levels of methionine, choline, and betaine”. *Poultry Science.* 85(1):90-95. doi: 10.1093/ps/85.1.90.

Poli A,and Visioli F .2019. Pharmacology of nutraceuticals with lipid lowering properties. *High Blood Pressure and Cardiovascular Prevention* .26(2):113-8. doi: 10.1007/s40292-019-00311-x.

Ramesh BK, Satynarayana ML, Gowda RN, Vijayasarathi SK, and Suguna Rao SR .2000.” Effect of *Lactobacillus acidophilus* on gut pH and viable bacterial count in experimental fowl typhoid in broilers”. *Indian Veterinary Journal*. 77: 544-546.

Raza A, Hussain J, Hussnain F, Zahra F, Mehmood S, Mahmud A, Amjad ZB, Khan MT, Asif M, Ali U, Badar IH .2019.” Vegetable waste inclusion in broiler diets and its effect on growth performance, blood metabolites, immunity, meat mineral content and lipid oxidation status.” *Brazilian Journal of Poultry Science*. 21(01). doi: 10.1590/1806-9061-2018-0723.

Reda FM, Alagawany M, Mahmoud HK, Mahgoub SA, Elnesr SS .2020. “Use of red pepper oil in quail diets and its effect on performance, carcass measurements, intestinal microbiota, antioxidant indices, immunity and blood constituents”. *Animal* .14(5):1025-33. doi: 10.1017/S1751731119002891.

Shambhvi, Katoch S, Chauhan P,and Mane BG .2021.” Effect of feeding *Azolla pinnata* in combination with direct-fed microbial on broiler performance”. *Tropical Animal Health Production*. 53:1-9. doi: 10.1007/s11250-020-02437-w.

Sharma S, Katoch S, Snakhyan V, Mane BG, and Wadhwa D .2023.” Effect of incorporating garlic (*Allium sativum*) powder and cinnamon (*Cinnamomum zeylanicum*) extract in an energy deficient diet on broiler chicken performance, nutrient utilization, haemato-biochemical parameters, carcass characteristics, and economics of production”. *Animal Nutrition and Feed Technology.* 23(2):303-317. doi: 10.5958/0974-181X.2023.00026.4

Sharma, kuber & Sharma, Arun & Suman, Madhu & Chauhan, Sunidhi & Katoch, Shivani. 2025. “Partial Replacement of Betaine on Broiler Birds Performance Partial Replacement of Betaine on Broiler Birds Performance Effect of Betaine Partially Replaced with Methionine on Performance and Carcass Quality of Broiler Birds”. *Indian Journal of Animal Nutrition*. 41. 10.5958/2231-6744.2024.00054.5.

Singh J, Sethi AP, Sikka SS, Chatli MK, and Kumar P .2014.” Effect of cinnamon (*Cinnamomum cassia*) powder as a phytobiotic growth promoter in commercial broiler chickens”. *Animal Nutrition and Feed Technology*. 14(3):471-479. doi: 10.5958/0974-181X.2014.01349.3.

Sirri F, Tallarico N, Meluzzi A, and Franchini A .2003.” Fatty acid composition and productive traits of broiler fed diets containing conjugated linoleic acid”. *Poultry Science* .82(8):1356-1361. doi: 10.1093/ps/82.8.1356.

Sittiya J, Yamauchi K, Nimanong W, and Thongwittaya N .2020.” Influence of levels of dietary fiber sources on the performance, carcass traits, gastrointestinal tract development, fecal ammonia nitrogen, and intestinal morphology of broilers*”. Brazilian Journal of Poultry Science* 22(01). doi: 10.1590/1806-9061-2019-1151.

Taklimi SM, Lotfollahian H, Shahne AZ, Mirzaei F, and Alinejad A .2012.”Study on efficacy of probiotic in broiler chickens diet”. *Agricultural Sciences.* **3**:5-8. doi: 10.4236/as.2012.31002.

Uni Z, and Ferket PR .2003.”Enhancement of Development of Oviparous Species by in ovo Feeding”. *U.S. Patent* 6,592,878. Yissum Research Development Co. of Hebrew University and North Carolina State University Raleigh, N. C.

Vasconcellos, R. S., Volpato, J. A., & Silva, I. C. (2024). Bioactive peptides extracted from hydrolyzed animal byproducts for dogs and cats. Animal frontiers : the review magazine of animal agriculture, 14(3), 38–45. https://doi.org/10.1093/af/vfae012

Wen C, Jiang XY, Ding LR, Wang T, Zhou YM (2017) Effects of dietary methionine on growth performance, meat quality and oxidative status of breast muscle in fast-and slow-growing broilers. Poult Sci 96(6):1707–1714. doi: 10.3382/ps/pew432

Xiao, Yong, Xuyang Gao, and Jianmin Yuan. 2024. "Comparative Study of an Antioxidant Compound and Ethoxyquin on Feed Oxidative Stability and on Performance, Antioxidant Capacity, and Intestinal Health in Starter Broiler Chickens" Antioxidants 13, no. 10: 1229. https://doi.org/10.3390/antiox13101229

Yadav S, Jha R (2019) Strategies to modulate the intestinal microbiota and their effects on nutrient utilization, performance, and health of poultry. J Anim Sci Biotechnol 10:1-1. doi: 10.1186/s40104-018-0310-9

Youn HS, Lee JK, Choi YJ, Saitoh SI, Miyake K, Hwang DH, Lee JY (2008) Cinnamaldehyde suppresses toll-like receptor 4 activation mediated through the inhibition of receptor oligomerization. Biochem Pharmacol 75(2):494-502. doi: 10.1016/j.bcp.2007.08.033

Zanella L, Vianello F (2023) Potential of microalgae as functional foods applied to mitochondria protection and healthy aging promotion. Nutraceuticals 3(1):119-152. doi: 10.3390/nutraceuticals3010010

**Table 1: Plant compounds along with their source and therapeutic use (Giannenas et al. 2020; Inoue, Hayashi, and Craker 2019)**

|  |  |  |
| --- | --- | --- |
| **Plant/ compound** | **Source** | **Therapeutic Use** |
| Oregano | *Origanum vulgare* | Anti-inflammatory, antioxidant, antifungal, antibacterial |
| Ginseng | *Panax ginseng* | Fatigue, stress |
| Aspirin | *Salix alba* | Anti-inflammatory, analgesic, antipyretic |
| Quinine | *Cinchona spp.* | Antiparasitic |
| Echinacea | *Echinacea purpurea* | Immunomodulator |
| Ginkgo | *Ginkgo biloba* | Antioxidant, Anti-inflammatory, stress, |
| Garlic | *Allium sativum* | Anti-inflammatory, antihypertensive, antihyperlipidemic, respiratory infections |
| Cinnamon | *Cinnamomum zeylanicum* | Antimicrobial, Anti-inflammatory, immunostimulant, antioxidant, antihyperlipidemic |
| Turmeric | *Curcuma longa* | Anti-inflammatory, antioxidant, antimicrobial,anticancerous |

|  |  |  |  |
| --- | --- | --- | --- |
| **Feed additives** | **Age** | **Treatment Effects (%, Compared to Control)** | **References** |
|  |  | **GIW** | **FI** | **FCR** |  |
| 0.5% Garlic powder | Upto 42 days | 7.97 | 1.18 | 7.22 | (Sharma et al. 2023) |
| 0.1% Cinnamon extract | Upto 42 days | 4.50 | 0.43 | 5 | (Sharma et al. 2023) |
| 0.1% cinnamon extract + 0.5% garlic powder | Upto 42 days | 7.20 | 1.15 | 6.66 | (Sharma et al. 2023) |
| *Spirulina plantensis* Algae 3% | Upto 35 days | 1.41 | 0.27 | -1.12 | (Ahmed et al. 2022) |
| *Spirulina plantensis* Algae 6% | Upto 35 days | 7.19 | 2.98 | -3.93 | (Ahmed et al. 2022) |
| Vegetable waste (cabbage 25%, cauliflower 50%, mustard 25%) 15 % | Upto 25 days | 19.19 | 30.09 | 9.3 | (Fitasari and Mushollaeni 2020) |
| CLA4(4% conjugated linoleic acid source containing 60% CLA methyl esters) | Upto 47 days | -0.77  | -0.50 | 0 | (Sirri et al. 2003) |
| Probiotic (Biomin Imbo 3 ×108cfu/g) at 0.15%, 0.075% and 0.0375% in starter, grower and finisher diets respectively. | Upto 49 days | 26.79 | -5.85 | -25.87 | (Taklimi et al. 2012) |
| *Achyranthes japonica* extract at 100mg/kg diet containing (flavanoid, polyphenol & saponin) | Upto 35 days | 3.5 | −2.4 | −6.2 | (Park and kim 2019) |

 **Table 2: Growth performance of feed additives**

**Figure.1 Emerging nutraceuticals and feed additives for better poultry production **