***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 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, physical properties of the feed to make it more suitable for processing and storage and nutritional value of the feed for better feed utilization in order 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 aging 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 diet. 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 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 herb 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, beet roots, 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 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 that methionine is involved in. 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 are vital to the body’s antioxidant defense 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 the fortified food with bioactive compounds that are designed or modified using technology or animal nutrition to offer potential health benefits, disease prevention, 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 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.*) has 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 has the ability to 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, 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 in a sustainable manner.

**Declarations**

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.

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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

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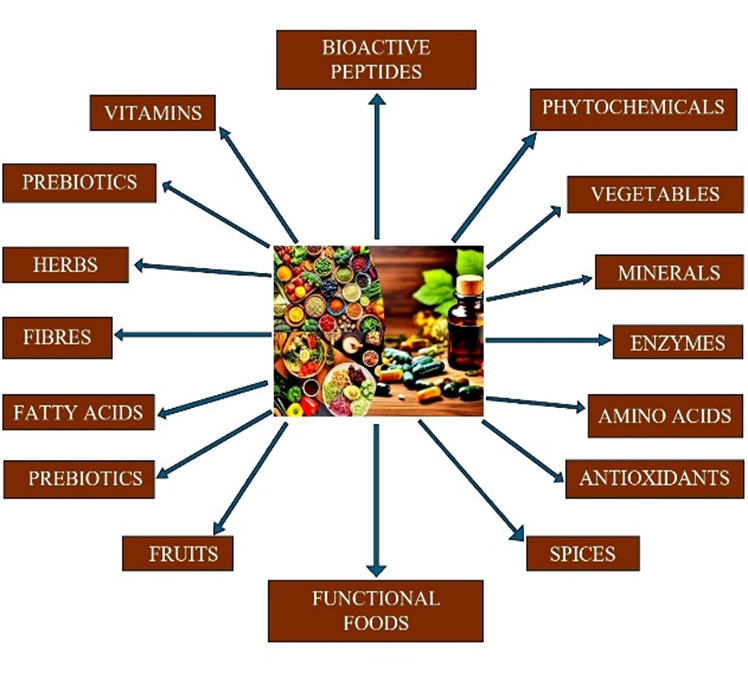
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**Table 1: Plant compounds along with their source and therapeutic use (Giannenas et al. 2020; Inoue, Hayashi, and Craker 2019)**

|  |  |  |
| --- | --- | --- |
| **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 **