Spirulina spp.

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Spirulina platensis (SP), a blue-green filamentous photosynthetic alga, is widely recognized as a valuable protein source, containing approximately 55–70% protein, 25% carbohydrates, essential amino acids, and 18% fatty acids. It is also rich in various vitamins and minerals. Notably, spirulina is known for its high content of thiamin, riboflavin, pyridoxine, vitamin B12, vitamin C, gamma-linolenic acid, phycocyanins, tocopherols, chlorophyll, beta-carotenes, and carotenoids.

Keywords: chickens ; spirulina ; turmeric

1. Introduction

Poultry production, particularly in developing regions, is experiencing rapid growth within the agricultural sector, making a valuable contribution to ensuring food security [1]. The rising demand for alternative feed resources is driven by factors such as intensified competition with other agricultural sectors over land, the impacts of climate change, and the ongoing need to enhance productivity and meat quality. Furthermore, there has been a growing focus on producing innovative functional foods using environmentally friendly sources [2].

Nutraceuticals refer to the essential nutrients or dietary components derived from animals that hold significant nutritional and pharmaceutical value. They exhibit immunomodulatory properties and play a crucial role in preventing diseases, promoting overall health, and subsequently enhancing productivity [3][4][5][6]. In addition, these nutraceuticals aid in safeguarding the host from infectious diseases [7], as well as influencing and sustaining essential physiological functions that contribute to the well-being of the host [8].

The term “nutraceutical” was coined in 1989 by Stephen DeFelice, combining the words “nutrition” and “pharmaceutical”. He clarified that a nutraceutical could encompass either a food or a component of food with the potential to prevent and/or treat diseases [9][10]. Since then, the term has been the subject of ongoing global discussions regarding its precise definition and scope.

Nutraceuticals encompass a wide range of substances, including isolated nutrients, such as vitamins, minerals, amino acids, and fatty acids. They also include herbal products, such as polyphenols, herbs, and spices, as well as dietary supplements, such as probiotics, prebiotics, synbiotics, organic acids, antioxidants, and enzymes. Additionally, nutraceuticals can extend to genetically modified foods [8][11][12].

Amino acids [13], minerals [14], and vitamins [15] play a significant role as common components in poultry diets, either individually or in combination [16][17], and can be considered as nutraceuticals with particular importance in poultry feeding. While natural feedstuffs generally provide essential nutrients for poultry, certain crucial amino acids (lysine, methionine, threonine, and tryptophan), vitamins, and minerals are often supplemented synthetically [18]. The refined form of these nutraceutical constituents in the diet can lead to improved digestion, absorption, utilization, and metabolism, ultimately resulting in beneficial health effects compared to conventional forms.

The nutraceutical value and conversion efficiency in poultry are subject to the influence of multiple factors, such as the genetic potential of the birds, environmental conditions, dietary quality, and gut health. Consideration of these factors is crucial for maximizing the productive efficiency of the birds [19][20][21].

In recent times, nutraceuticals have garnered significant attention in poultry science. This is attributed to the recognition of the nutritional and healthier attributes of feed ingredients, as well as growing concerns regarding the adverse effects associated with chemical pharmaceuticals, such as antibiotic resistance and the presence of drug residues [22][23].

The use of antibiotics in poultry has been known to reduce the microbial load in the gut, thereby increasing nutrient availability for the host [24]. However, concerns regarding the development of antimicrobial resistance and the transfer of

antibiotic-resistance genes from animals to human microbiota prompted the European Union to ban the application of antibiotics as growth promoters from 1 January 2006 [25]. The removal of antibiotic growth promoters (AGP) from poultry diets has resulted in challenges related to animal performance and an increase in the occurrence of certain poultry diseases, such as subclinical necrotic enteritis and dysbacteriosis [26]. Consequently, there is a pressing need to find alternatives to AGP.

Ideally, these alternatives should provide similar beneficial effects as AGP. In recent years, there has been a significant increase in nutrition-based research focused on finding alternatives to AGP in various farm animals, including poultry [26].

In this context, nutraceuticals have been discovered to possess numerous beneficial health applications and potential roles in improving production performances in poultry. They serve as antioxidants in promoting health, modulating the composition of gut microbiota, and enhancing poultry immunity [3][11][27][28][29].

2. *Spirulina spp.*

The utilization of microalgae as a feed ingredient offers several advantages in terms of environmental protection and conservation of natural resources, including the prevention of land degradation and water scarcity issues [30]. In the field of poultry nutrition, there is a growing trend toward the incorporation of natural ingredients as alternatives to antibiotics, growth factors, and other chemical substances.

Spirulina platensis (SP), a blue-green filamentous photosynthetic alga, is widely recognized as a valuable protein source, containing approximately 55–70% protein, 25% carbohydrates, essential amino acids, and 18% fatty acids. It is also rich in various vitamins and minerals. Notably, spirulina is known for its high content of thiamin, riboflavin, pyridoxine, vitamin B12, vitamin C, gamma-linolenic acid, phycocyanins, tocopherols, chlorophyll, beta-carotenes, and carotenoids [31]. Recent studies have demonstrated that spirulina exhibits positive effects on growth performance, gut integrity, and immunity. Additionally, it has shown modulating activity and has been associated with various pharmacological properties.

Several studies have been conducted to investigate the potential benefits of SP in broilers. These studies have explored its use as a growth promoter [32][33], regulator of gut health [34], immune stimulator [35], and enhancer of meat yield and quality [2]. These studies have reported various findings highlighting the positive effects of SP in these different aspects of broiler production.

A significant and expanding body of research has provided evidence for the immunostimulatory, hepatoprotective, anti-inflammatory, antimicrobial, antiviral, and antioxidative activities of SP [36][37]. These activities are attributed to its ability to enhance disease resistance, stimulate the production of antibodies and cytokines, effectively scavenge free radicals, and inhibit lipid peroxidation. Consequently, the inclusion of SP in poultry production has shown promising results in improving overall production outcomes and attaining greater profitability [38][39][40][41].

Spirulina has gained recognition for its diverse biological effects, including the prevention of anemia due to its high iron and vitamin content [42]. It has also shown a potential to inhibit herpes simplex infection [43]. Studies have revealed that the ethanolic extract of SP contains various bioactive compounds, such as alkaloids, flavonoids, glycosides, tannins, phenolic compounds, steroids, and saponins [44].

Numerous studies have indicated the therapeutic effects of spirulina. It has been shown to reduce cholesterol levels and potentially have anticancer properties by enhancing the immune system. Additionally, spirulina has been found to increase the population of beneficial intestinal lactobacilli, reduce nephrotoxicity caused by heavy metals and drugs, and offer radiation protection [45]. Furthermore, spirulina is widely recognized for its antioxidant properties, which can be attributed to molecules such as phycocyanin, beta-carotene, and tocopherol. These antioxidant properties contribute to spirulina's ability to inhibit carcinogenesis and mitigate organ-specific toxicity [46].

Phycocyanin (PC) is a blue pigment found in cyanobacteria and certain red algae of the phycobiliprotein family. It is soluble in water and primarily located in the cytoplasmic membrane. However, it can be released outside the cells when the thylakoid membrane is disrupted by lysozyme enzymes and EDTA-chelated cations [47][48]. PC exhibits a range of beneficial properties, including antioxidant, radical scavenging, anti-inflammatory, anti-arthritic, hepatoprotective, antitumor, and immune-enhancing activities [49][50]. In broiler production, natural antioxidants are preferred due to their health-promoting characteristics [51]. These antioxidants help reduce the production of reactive oxygen species (ROS) and subsequent oxidative stress [52].

In the current global market, there is significant competition between microalgae carotenoids and artificial, synthetic, and unnatural pigments [53]. Despite their relatively high cost, natural algae are used in smaller quantities and have no known side effects [54].

Similar to other animals, the digestive tract of poultry plays a critical role in the utilization and intake of feed while also being important in terms of exposure to environmental pathogens [25]. Any functional disturbances in the digestive tract can pose risks to the health and performance of poultry, as it can disrupt the absorption and digestion of nutrients. The small intestine is particularly crucial for nutrient absorption [55]. The intestinal mucosa plays a vital role in enhancing nutrient absorption and acts as a barrier between the internal tissues of the host and the intestinal contents, thereby serving as an immune defense mechanism [19]. The proper functioning of the mucosal layer is the result of a delicate balance between the mucosal layer, epithelial cells, immune cells, and the microbiota [56].

The intestinal microbiota plays a crucial role in maintaining immune homeostasis and regulating inflammatory responses [57]. Commensal bacteria in the intestine produce short-chain fatty acids (SCFAs), which have anti-inflammatory properties and help protect against intestinal injury [58]. Modulation of the intestinal microbiota can be achieved by incorporating nutraceuticals into the poultry diet. Nutraceuticals have the potential to promote the growth of beneficial bacteria while suppressing the growth of harmful bacteria [59]. This modulation of the intestinal microbiota can have significant implications for the overall health and well-being of poultry.

The gut microbiota plays crucial roles in the regulation of epithelial cell proliferation in the gut, synthesis of vitamins, and host energy metabolism. In poultry, the gastrointestinal tract (GIT) harbors a complex and dynamic microbiome primarily composed of bacteria, with a lesser presence of fungi, protozoa, bacteriophages, yeast, and viruses. This diverse microbial community has significant impacts on various aspects of poultry health and physiology.

Microbes within the gastrointestinal tract (GIT) interact extensively with the host and the consumed feed. Different regions of the GIT harbor distinct populations of microbes, creating specific niches [21]. In chickens, imbalances in the gut microbiota have been associated with adverse effects on intestinal health [60][61]. It is widely acknowledged that maintaining an appropriate microbial balance, with favorable bacteria comprising about 85% of the total bacterial population, is crucial for the host's well-being [62]. The elimination of antibiotics from feed further compounds bacterial imbalances. Correspondingly, Kabir demonstrated that a balanced gut microbiota is vital for maximizing chicken growth performance and promoting a healthy gut [63].

Fortunately, dietary interventions, in conjunction with promoting the growth of beneficial bacteria in the chicken intestine, can be used to modulate the gut microbial population [59]. Studies by Humphrey and Klasing have shown that changes in the microbiota can impact gut wall morphology, elicit immune responses, and ultimately influence energy expenditure and chicken development [64]. These findings highlight the importance of maintaining a healthy and balanced gut microbiota for optimal poultry growth and overall well-being.

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