Review Paper:

Spirulina-based poultry feed: opportunities, challenges and future prospects

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Abstract

There is a concerted effort to find newer sources of feed additives that are not only economically viable but superior in nutritional composition and less dependent on agricultural crop sources that are primarily intended for human use. Furthermore, as a commercial enterprise, it is essential for the development of the poultry sector to maximize earnings in a sustainable manner. Meat and egg prices are highly volatile, being determined mostly by market forces at the expense of feed. Many problems in the poultry business could be addressed by exploring the potential of microalgae as an animal feed ingredient.

Typically, the protein content of the substituted feed component should be high, have a well-balanced amino acid profile, be easily digested and not pose any nutritional risks to the bird. Green technology is introduced into the poultry sector value chain through the use of microalgae-based feed supplements which provide sustainability and carbon-capturing potential during the algae production phase. Microalgae such as Spirulina (Arthrospira sp.) can be used as a feed resource for chickens because of their high nutritional value. Animals fed with a diet consisting of spirulina showed improved growth and development, resistance to diseases, improved fertility and enhanced aesthetic and nutritional quality of their products. However, there is a significant gap in our understanding of how animals respond to Spirulina in the diet. Thus, this study examines the history and present state of knowledge concerning the use of Spirulina as a poultry feed additive, as well as the industry's current and future opportunities, challenges and prospects.

Keywords: Feed efficiency, Egg production, Feed intake, Microbiology, Yolk colour, Microalgae.

Introduction

United Nations Department of Economic and Social Affairs, Population Division, predicts that in 2050, the world's population will hit 9.7 billion. This would lead to a rise in poultry meat production to approximately 200 million tons[3]. Considering the scarcity of water and farmland, it would be extremely challenging to provide enough protein for broiler chickens. Current crop yield growth of 0.9% to 1.6% per year is expected to fall short of the expected doubling of soybean and other feed plants needed to meet poultry feed supply needs by 2050[95]. Still, an evaluation of the general public's tolerance for a diet heavy in poultry-based nutrients and high-quality proteins suggests that the poultry sector is lucrative and provides increased food security[75].

By virtue of its high monounsaturated fatty acid content and low total fat, chicken meat is considered by the Food and Agriculture Organization (FAO) to be the healthiest option among other red meats. In many regions of the world, domestic small-scale poultry production is a vital source of revenue for smallholder farmers, improving the standard of living in rural areas with low per capita income[78]. It is anticipated that Europe will soon take a major position in the global ranking of the microalgae-based markets which are currently led by Asia, the United States and Oceania.

A survey conducted in 2017 estimated a global market for microalgae products to be worth roughly US$33.60 billion with projections indicating that this number will increase to an average of US$54.43 billion by 2026. The majority (about 75%) of these goods are manufactured for use in the animal feed, food and nutraceuticals industries and this share is expected to grow as the market for health food items expands[92].

Poultry farmers must ensure their birds have access to a balanced diet high in protein. Multiple strategies are needed to address this "protein gap" such as reducing crude protein, enhancing amino acid digestibility and turning to new protein sources[29,86,100,103]. Algae and other naturally occurring functional ingredients provide an exciting new direction for the creation of novel foods[40,69].

Spirulina (*Arthrospira sp.*) is one of the most nutritious edible algae since it contains many beneficial bioactive components. Because of its high protein content (260-770 g/kg DW) and beneficial lipid content (10-140 g/kg), dried spirulina is an excellent dietary source[10,16,36,53,99,117,134]. According to several studies, Spirulina has a better amino acid profile and is more nutrient-dense than other plant-based diets and feeds[10,88,117]. In addition, Spirulina has been utilized all over the world as a feed component in broiler and layer diets to improve yolk color, meat quality and egg fertility since it is a rich source of carotenoids and fatty acids, particularly gamma-linolenic acid (GLA)[52,99]. Spirulina's carotenoids are a good source of vitamin A, which helps to

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regulate hormones and has an important role in growth, reproduction and maturation[82].

The Food and Drug Administration (FDA) has recognized Spirulina as a safe supplement with no known toxicological effects. Spirulina's nutritional profile including protein, vitamins, lipids, fibers, minerals, carbs and some natural pigments makes it a useful addition to the food business and an effective tool in the fight against malnutrition and other health issues[12,16,50]. Spirulina is an excellent source of antioxidants[90]. Spirulina has a large and diverse collection of flavonoids and phenolics which are known to have antioxidant properties. Such components contribute to antioxidant and antibacterial effects[32].

Compared to control birds, hens fed with a diet containing Spirulina were able to produce and reproduce at significantly higher rates[82,99]. Both the rate of weight gain and the total body mass of the Spirulina-supplemented birds were significantly higher than those of the control birds[64]. The increased growth in size is attributed to feed composition and nutrients[72]. Furthermore, it was found that chicks fed 6 g/kg spirulina had the highest feed conversion ratio[47].

In addition, several studies have shown that including Spirulina in the feeds of laying hens greatly improve the yolk color of the eggs[34]. The color of egg yolks can be improved through the use of nutritional supplements containing carotenoids. Plants, algae, fungi and some bacteria are capable of synthesizing carotenoid pigments. The impact of dietary Spirulina on the hue of egg yolks has been the subject of research. Because of the increased beta-carotene in Spirulina, the yolks turn out brighter and more vibrant in color. The egg yolk color score improved linearly and quadratically after supplementation with *Spirulina platensis*[102].

There was a significant increase in egg yolk coloration from a score of 6.3 to a score of 7.6 when Spirulina was included in the diet at 0.1- 0.2%[73]. Egg yolk color scores improved from 10.55, 11.43 and 11.66 when supplemented with 2, 2.5 and 2.5 percent spirulina, respectively, compared to the control group in a study by Zahroojian et al[134].

The tough cell walls of most microalgae impede digestion by monogastric animals and, consequently, the absorption of their nutrients[15,70,109]. Spirulina's cell wall serves as an efficient barrier, protecting the intracellular nutritious components and easing digestion[109]. It has been hypothesized that microalgae digestibility is affected by the intrinsic cell wall structure, nutritional makeup and digestive physiology of the animal species that consume them[86].

The use of exogenous enzymes has been a common practice in animal nutrition, especially in the improvement of the nutritional value of poultry feed[113]. Feed-encapsulated enzymes, particularly phytase[39] and carbohydrate-degrading enzymes, improve feed conversion[35]. The use of exogenous enzymes has the potential to generate prebiotic oligosaccharides that alter the composition of the animal's resident microbiota and improve the animal's health[14,18,19].

Moreover, the use of exogenous enzymes decreases feces production, which in turn lessens negative impacts on the environment[35]. In addition to promoting faster growth and better-quality carcasses, Spirulina has been linked to multiple beneficial attributes[7,43,85,125,128].

Microalgae have multi-layered cell walls that are extremely complicated. The components of cell walls are polysaccharides, proteins, lipids and inorganic ions. Several nonthermal technologies have been investigated for their potential to disrupt the cell wall[74]. Lipids were extracted from microalgae using a nonthermal technique by altering the microstructures of the cell walls using microwave treatment (MW). The cell wall was ruptured by raising the temperature from 80 to 120 °C using MW[132]. Different types of microalgae can have their cell walls broken down by ultrasound (US), allowing more efficient recovery of cellular constituents[74].

High-pressure (HP) treatment (300-600 MPa/15 min) was recently studied by Ahmed and Kumar (2022) to determine its effect on the rheological properties, thermal properties, structural properties and particle size distribution of dry powdered Chlorella and Spirulina. Research into the algal biomass's post-harvest handling is useful for the creation of food and feed products made from the biomass, which has a thick cell wall.

Application of Spirulina as a feed additive

For decades, people have used Spirulina in animal feed. In 1949, Spoehr and Milnerly proposed that the high protein content of Spirulina could aid in the global fight against protein deficiency[80]. It has been discovered that algae are rich in the amino acids lysine and threonine[80]. Spirulina is a promising new source of nutrients having a wide variety of vitamins and minerals in its dry matter[46]. The use of Spirulina-based proteins can contribute to less adverse impact on the environment. For instance, cost-effective production of protein-rich microalgae can reduce the amount of soybeans and other plant-based proteins used in animal feed diets[56].

When compared to soy meal, Spirulina's gross energy, dry matter, calcium, crude protein, mineral matter and total phosphorus levels are significantly higher. Spirulina has 98 kcal more metabolizable energy per kilogram of dry matter than soybean meal[10]. The high protein content of *S. platensis* makes it a viable food source for broiler chickens[26]. In 2018, Park's group conducted experiments showing that when broiler chicks were fed diets containing Spirulina, both the dry matter and nitrogen digestibility rates enhanced[85].

People have been consuming *Spirulina platensis* for a very long time. Spirulina was a staple diet for the Aztecs in

Mexico and for locals in the Lake Chad region more recently[36]. The food coloring and supplement markets have benefited greatly from the commercial production of Spirulina, which has been going strong for the past 20 years. Although Spirulina is widely utilized as a food supplement for humans, its use as an animal food supplement is a relatively new phenomenon. On the other hand, over 30% of the present global production of Spirulina is sold for animal feed purposes[23]. As a result, Spirulina has earned the label of "superfood".

Spirulina is grown in large quantities in raceway ponds. It is recommended that temperatures be kept between 30 and 35^{0}C for maximum output[115]. Scalable production of Spirulina is possible in both freshwater and wastewater. In the pH range of 9–11, bicarbonate ions are essential for Spirulina's selective and optimum growth[36]. In this pH range, most contaminants die off or cannot grow. There is consequently less chances of cross-contamination with other bacteria. Moreover, Spirulina cultivated in sewage sludge can be used as animal feed[126].

Spirulina vs other feed ingredients: Biochemical composition

Spirulina has greater amounts of dry matter, gross energy, crude protein, mineral matter, calcium and total phosphorus and lower amounts of crude fiber than soybean meal. Spirulina is rich in calcium and phosphorus because they play important roles in microalgae metabolism. When comparing the energy content of Spirulina and soybean meal, the former has a greater gross energy content (9.6%), an even higher apparent metabolizable energy (9.8%) and an even higher clear metabolizable energy (6.7%) after adjusting for nitrogen[97].

Soybean meal has 1.39% methionine and bran corn gluten has 2.46% methionine and cystine while Spirulina has even more of these sulfur-containing amino acids, according to the study by Rostagno et al[98]. Keeping the optimum protein concept in mind, switching to Spirulina from soybean meal reduces the amount of added synthetic methionine.

Depending on the source, spirulina's protein content can be as high as 55–70% by dry weight. As a result, Spirulina can be a primary food source for people who are protein deficient. Leucine, valine and isoleucine are the amino acids found in proteins in the greatest abundance[16,21]. Among the lipid components of Spirulina, polyunsaturated fatty acids make up a significant portion (1.5-2%, out of a total lipid composition of 5-6%).

In 2008, Habib and colleagues performed an analysis of the fatty acids in Spirulina and found that polyunsaturated fatty acids (PUFAs) accounted for 30 percent of the total lipids[53,61]. Spirulina also contains significant amounts of several other minerals including potassium, calcium, chromium, copper, iron, magnesium, manganese, phosphorus, selenium, sodium and zinc. In addition, its iron content is twelve times higher than that of any other meal and it is also rich in magnesium, potassium and other trace elements[51]. Spirulina is a great source of multiple vitamins, including vitamins A[83], B1, B2, B3, B6, B12, C and E.[126] A wide variety of pigments, such as chlorophyll-a, xanthophylls, -carotene, echinenone, myxoxanthophyll and the phycobiliproteins C-phycocyanin and allophycocyanin can be found in abundance[126].

Effect of supplementing Spirulina in chicken diets

There has been an increase in the consumption of chicken and turkey over the past few years because of the cost and health benefits compared to the red meat[30,87]. Therefore, including Spirulina in broiler diets has been shown to have positive effects on the animals' performance and health[4,6,42,58,65,76,79,94,99,106,124,128], making it a viable option for satisfying consumer demand for healthy, naturally-sourced foods[63].

Growth enhancement: Ross and Dominy[99] found that feeding male broiler chicks 1.5–12% Spirulina in place of conventional protein sources significantly increased the rate of growth and efficiency of feed conversion. Experiments were conducted on male broiler chicks fed Spirulina-containing diets for 41 days. Additionally, the study found that dried Spirulina may effectively replace other protein sources in broiler diets and chicks at a dietary concentration of less than 12%[99]. Supplementing feed with 5-10% Spirulina was proven to be effective in boosting growth and egg production in chickens[17,25,28,81,128,133].

Egg quality and improved yolk colour: In addition, feeding of spirulina helps improve the color and appearance of egg yolks[13,25,37,99,128]. In addition, laying hens can benefit from Spirulina as a nutritional supplement[5] since it provides an additional mineral and protein source that enhances meat and egg quality without causing any negative side effects[102,117,121].

Vincenzo et al[129] found that feeding 2% spirulina to laying hens altered the thickness and strength of their eggshells. In a similar study, Selim et al[102] found that including 0.3% Spirulina powder in the diet increased eggshell thickness. The calcium in Spirulina may be responsible for this effect. Calcium content of Spirulina is around 26 times higher than that of milk[131]. These investigations are at odds with those conducted by Zahroojian et al[134] who found that feeding laying hens a diet containing 2.5% Spirulina had no discernible influence on egg characteristics.

People all across the world have a strong preference for yellow or even golden yellow yolk[57,66]. It has been found that flavonoids and carotenoids are helpful in the formation of yolk color, with Garcia et al[49] reporting that giving poultry diets containing flavonoids led to increased pigment in the yolk which controlled the color intensity. Spirulina's ability to alter egg yolk color is mostly attributable to the carotenoids, specifically beta-carotene. The yolk is a prime location for the storage of carotenoids[102,134]. Ross and Dominy[99] found that the color of egg yolks improved in direct correlation with the amount of Spirulina in the diet.

Improvement in other parameters: Spirulina biomass supplementation at low levels (0.02 or 0.03%) enhanced not only the growth performance of broilers but also their blood histology, the dressing percentage of their meat, the meat color score and the weight of their lymphoid organs while reducing their relative abdominal fat weight, blood triglycerides, lymphoid organs and total lipids[73]. Additionally, feeding layer hens a diet that included Spirulina, reduced cholesterol in the eggs and boosted omega-3 fatty acid levels[120].

Several studies have shown that supplementing broiler diets with Spirulina (5 g/kg or 10 g/kg) alters the content of fatty acids in broiler meat without significantly affecting performance indicators or oxidative stability. Polyunsaturated fatty acids like EPA, DPA and DHA, which are essential to human health, were also shown to be more concentrated in thigh meat when 5 g/kg Spirulina was included in the diet[26]. Because of Spirulina's high nutrient content, vitamin and mineral premixes typically added to broiler feed rations can be omitted. In addition, Spirulina-supplemented chickens fared better than their non-Spirulina-fed counterparts[128]. As a result, chickens may be better able to fend against disease, a phenomenon that may be attributable to the enhanced function of macrophages and the mononuclear phagocyte system[2,91].

It was found by Qureshi et al[91] that incorporating very little amount (10 g/kg) of dietary Spirulina into the feed was enough to enhance chicken health and ultimately lead to more cost-effective production. Bonos and co-workers found that changes in fat intake altered the fatty acid profiles of both thigh and breast meat. However, thigh meat was far more effective[26]. This distinction may be due to the fact that raw chicken thighs contain anywhere from 40 to 140 grams of crude fat per kilogram while raw chicken breasts have just about 10 to 30 grams of fat per kilogram. Perhaps due to their varying phospholipid concentrations, the fatty acid composition can also vary amongst these various muscle tissues. Endogenous fatty acid production and feed-indirect fat consumption both contribute to these compositional variations[27,38]. Furthermore, Cortinas et al[38] suggested that the overall amount and the individual fatty acid ratio in the subcutaneous fat and meat might be directly affected by the incompatibility of fat sources in broiler diets.

Since humans lack the enzymatic machinery to produce them, polyunsaturated fatty acids must be obtained through the diet[44]. Consumption of these fatty acids is essential for the synthesis and metabolism of important chemicals such as prostaglandins, thromboxanes and leukotrienes[44,111]. According to research by Bonos and colleagues, thigh meat, known for its high nutritional value, contains a high amount of the n-3 fatty acids eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA) and docosahexaenoic acid (DHA)[26]. However, most people do not get enough of these fatty acids in their diets[111].

Consumption of these foods has been shown to benefit foetal development and may protect against cancer, asthma, infections, heart diseases and autoimmune disorders[44,110,122]. Further, lowering one's intake of saturated fatty acids and raising one's intake of unsaturated fatty acids has been found to lower the risk of cardiovascular and degenerative diseases and their consequences[38,44,96]. As a result, Spirulina is now recognized as a beneficial functional element in diets.

Alternative to antibiotics or pro- and prebiotic effects: The use of antibiotics as a supplement in animal feed (in-feed antibiotics) is growing to protect poultry from infectious diseases. Broiler production benefits from "in-feed antibiotics" due to their ability to decrease mortality and morbidity[118]. However, in several countries, the use of antibiotic additions has been banned because of the rise of antibiotic-resistant microorganisms. Unfortunately, many health issues and decreased productivity can be traced back to the elimination of additives in poultry feed[89,118]. Therefore, finding suitable replacements for antibiotics in feed is essential for ensuring the safety of our food supply.

From the time of hatching to the time of slaughter, Spirulina was fed as an in-feed ingredient in place of antibiotics[26,62]. Due to the presence of polysaccharides, Spirulina can serve as a prebiotic[20]. Increase in body weight and a decrease in feed conversion ratio (FCR) were seen in broilers fed 2, 4, or 8 g of Spirulina platensis per kg feed[62]. Shanmugapriya et al[104] documented increase in the length of villi and consequently their ability to absorb nutrients when chicks were fed with 1% Spirulina. From a health perspective. Feeding Spirulina to the broilers resulted in a decrease in *Escherichia coli* and increased the abundance of lactic acid bacteria (LAB) in the gastrointestinal tract[105].

Broilers that were fed a diet rich in Spirulina had better cellular and humoral immune responses and had fully developed lymphoid organs[91,93]. Lokapirnasari et al[68] stated that Spirulina can boost leukocyte counts and survival rates. Spirulina's anti-inflammatory, anti-bacterial and antioxidant characteristics may attribute to the health-promoting factor in chickens[46,58,64,93].

Spirulina is more expensive than other antibiotics and feed additives[58]. Despite its advantages, replacing antibiotics with Spirulina all through the raising process of chickens seems to be unfeasible in the current scenario. For this reason, nutritionists should develop effective feeding regimes for broilers in order to cut down on microalgae costs and quantities used in poultry production[118]. Sugiharto and his team fed Spirulina to broilers for the first 21 days and the results showed that growth and performance were comparable to those obtained after prolonged dosing with Spirulina or antibiotics during the rearing process.

Table 1
Studies related to the effects of *Spirulina* on poultry

Parameter	Summary of the results
Broiler Feature	Yolk colour was increased due to carotenoid accumulation. *Spirulina* was fed at 1.5-12 g/kg for 41 days[25,99].
	Spirulina (40 g/kg) in broiler feeds enhanced pigmentation (yellowness or redness) in meat[125].
Health	Broiler chickens supplemented with Spirulina and other algae enhanced cellular and humoral immune status and promoted healthy microflora in the guts[4] Comprehensive review of immune modulatory effects of Spirulina as a feed additive in chicken[42] In vitro therapy of macrophages with a water extract of *Spirulina* resulted in enhancement in macrophage activation (phagocytosis)[91].
	Feeding *Spirulina* to Leghorn chickens (up to 10 g/kg) resulted in higher natural killer cell (NK) activity, larger thymi and cutaneous basophil hypersensitivity (CBH) response[91].
	The amount of phagocytic macrophages was increased in the *Spirulina*-fed group[91].
	Higher bacterial clearing rates were seen with *Spirulina* supplementation compared to the control diet[91]. A positive effect on body weight gain, feed conversion ratio and villus length in the group fed with 1 g/kg *spirulina*[104,105]
Growth Performance	Supplementing *Spirulina* up to 2 g/kg in feed improved growth performance, gut integrity and immunity of broiler birds[101].
	Broilers fed with *Spirulina* up to 10 g/kg of diet had similar body weights after seven weeks[91]
	Feeding a 2 g/kg *spirulina*-supplemented diet lowered total cholesterol in the yolk, a positive feature related to consumer health[129] Dietary levels of 16 g/kg *spirulina* resulted in improved digestibility of methionine[43]

Therefore, feeding Spirulina throughout the life cycle may not be necessary to improve their development and productivity[118]. Table 1 summarizes the findings of the most important studies on the effects of Spirulina on poultry.

Major Challenges and Future Aspects of Spirulina in Poultry

Spirulina's high price is a major constraint to its widespread use in the poultry sector. The high cost of production further affects the widespread adoption of Spirulina in poultry. Although Spirulina has the potential to supply up to 50% of the protein diets in feed, it is not likely to be used in this capacity due to the availability of low-cost protein sources like Soybean meal[23]. The cost analysis of Spirulina versus other feed supplements shows that there should be a concerted effort to develop technologies to produce Spirulina cost-effectively as the current price of Spirulina is significantly greater than any other supplements such as fish meal, soybean meal, wheat and corn. The possibility for negative effects exists, even though Spirulina is generally accepted as safe around the world. Instances, where this is the case, include the consumption of Spirulina that has been contaminated with toxins. As a result, despite Spirulina's widespread nutritional uses, its industrial production is still restricted to only a few locations.

Furthermore, there appears to be a lack of attention paid to research into the genetic engineering of Spirulina[107]. There is a need for future studies particularly in the areas of cultivating Spirulina in novel ways and developing effective genetic and molecular biology tools for the easy environmental adaptability of the algae[107]. This can facilitate the commercialization of Spirulina and the generation of high-quality biomass rich in nutrients[108].

In addition, various toxicological, clinical and scientific studies are required to evaluate the safety of commercially produced microalgae with harvest at minimal contamination rates due to the hazardous contamination of elements or toxic chemicals which may cause serious human health issues[107].

Several small-scale enterprises have recently focused on Spirulina production because of its high demand and reputation as a 'superfood'[112]. Francesca and his group[48] found that the cultivation of Spirulina uses less water and less land than any other high-yield vegetable protein source; also, Spirulina can aid with high yields and can assist minimize green gas emissions due to its CO_2 fixation potential. Furthermore, the aggregate biomass of microalgae harvests can be employed as a nutritional supplement or component.

In addition, Spirulina value chain has room for improvement in terms of sustainability[48]. The water supply has surpassed all other resources as the most used commodity[127]. Accordingly, Spirulina production on a large scale is being negatively impacted by the current global water crisis[48].

Annual production of Spirulina in the markets for producing microalgae biomass is predicted to be over 12,000 tons[67,77]. Despite the growth of the industry, the high cost of processing and producing Spirulina has kept it from being widely used as a protein substitute. Even though advances in the industry and production technology can overcome these problems, the main issue that needs immediate attention is the cost-effective production of biomass with all the safety compliance. Wang et al[130] proposed adopting photobioreactors to increase Spirulina production due to its ability to carefully control contamination, at moderate operational cost, to establish sustainable techniques for biomass production and extracting bioactive products.

Spirulina supplementation improved the taste and texture of meat from broiler chickens. Altmann et al[8] found that meat raised on Spirulina feed had a deeper color, with more saturated tones of red and yellow in both the breast and thigh. When substantial amounts of Spirulina are consumed, the color of poultry flesh changes to orange. According to the findings of a study on consumers' preferences for the visual appeal of poultry products, shoppers did not prefer poultry fed with Spirulina unless they were given background information on the unusual color[9].

The green color, fishy flavor and odor and powdered nature of Spirulina have made it unappealing for use in some traditional products. Depending on their structure and environment, as well as preservation, packaging and shelf-life factors, microalgae functional compounds' stability and bioavailability may pose a challenge. Microalgal biomass production in closed photobioreactors poses several technological problems and increases energy consumption rates. Many research groups are striving to improve the efficiency of microalgal photobioreactors which have been employed to boost biomass recovery in recent years[31].

Spirulina's environmental cost varies greatly depending on how it is grown, where it is grown and how it is used in relation to other protein sources[114]. For instance, Spirulina production is not more eco-friendly than soybean production. To make production more sustainable, however, several improvements are necessary. As such, scientists are investigating the potential of using biogas effluent[60] or wastewater as nutrient sources to further enhance sustainability. In addition, since Spirulina thrives in warm temperatures (35-37 °C)[53], incorporating waste heat sources, such as those generated during biogas production, may enhance profitability[123].

In addition, increasing manufacturing capacity and improving efficiency will be critical in addressing these problems. Last but not least, the food industry should implement regulations so that the consumers feel safe and this can only be achieved by legislation and regulations for using biomass or coproducts derived from microalgae[31].

Conclusion

Spirulina is a promising protein-rich feed ingredient for poultry production. There have been numerous studies and experiments conducted to determine the nutritional value of Spirulina and its impact on broiler development and the quality of their eggs and meat. Furthermore, Spirulina can be used in place of traditional protein sources, primarily soybean meal, in poultry feed.

Large-scale production of Spirulina presents some challenges due to the requirement of fresh water and the high cost of production; however, these issues need to be addressed through technological advancements in the field of genetic screening, strain improvement and engineering.

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