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The effect of Spirulina inclusion in broiler feed on meat quality: recent trends in sustainable production

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Abstract. This review covers the current situation of the use of Spirulina in poultry diets and discusses its benefits and challenges with particular emphasis on the effect of Spirulina supplementation on production performances and meat quality. Feed enriched with Spirulina influences broilers' health by improving their immune response and gut function and increasing PUFA and pigment content in the meat. However, despite numerous studies, the effect of Spirulina on broiler performance remains unclear.

1. Introduction

Poultry meat is among the most common animal-origin foods consumed worldwide due to its nutritional composition. Poultry production is one of the fastest-growing agricultural subsectors, especially in developing areas, effectively contributing to food security [1]. Increased competition for land with other agricultural sectors, climate change, and the constant need to increase productivity and improve meat quality has resulted in demand for novel feed resources. Moreover, in recent years, there has been an increased interest in the production of innovative functional foods using eco-friendly sources [2]. One of the promising sustainable ways to meet the aforementioned criteria is the use of Spirulina (*Arthrospira* spp.), which is a filamentous, spiral-shaped, blue-green microalga [3]. Spirulina is suitable for use as a feed supplement and feed ingredient for poultry due to its high protein content (up to 65%), rich in all essential amino acids [4]. In addition, Spirulina contains high amounts of physiologically active substances, including carotenoids, phycocyanin, polyunsaturated fatty acid (PUFA), vitamins, macro, and micro-minerals. These substances exhibit antimicrobial, antioxidant, and anti-inflammatory properties [5,6,7]. Considering recent trends, toward sustainable production, this review aims to discuss the benefits and challenges of using Spirulina as a feed ingredient in poultry feeds and its consequent effect on meat quality.

2. Materials and Methods

A review was performed by analysing scientific research and review papers from the scholarly databases and technical reports published in the domain of microalgae use in poultry diets.

3. Discussion

3.1. The effect of Spirulina supplementation on production traits

Results regarding production parameters in broilers fed Spirulina differ between studies. Some authors [8,6,9] reported that even low (10g/kg diet) levels of inclusion of *Spirulina platensis* significantly increases body weight gain (BWG), while decreasing feed conversion ratio (FCR). Moreover, Mariey *et al.* [10] found that broilers supplemented with 0.2 and 0.3g Spirulina/kg diet improved FCR by 10 and 12%, respectively, compared with the control group. They also reported increased dressing percentage and decreased relative abdominal fat weight. An increase in feed intake (FI), BWG, and better FCR were observed with 2 g of Spirulina/kg feed supplementation by Khan *et al.* [9]. Similar results were reported by Alwaleed *et al.* [11], with the inclusion of 10 g Spirulina/kg feed. These results are attributed to previously reported healthy effects of Spirulina, in terms of increased immune response and beneficial influence on gut histology and microbiota. Various studies showed that Spirulina enhances the immune response [7]. The proposed hypothesis is that Spirulina increases macrophage functionality and, overall, the mononuclear phagocyte system [12]. Seyidoglu *et al.* [13] suggested that β-glucan and phycocyanin from Spirulina influence the development and maturation of leukocytes. Lokapirnasari *et al.* [14] and Jamil *et al.* [15] found a higher number of leucocytes in broilers supplemented with Spirulina, compared to control broilers, while Fathi *et al.* [16] reported that the addition of *S. platensis* resulted in a higher weight of immune-system related organs. Park *et al.* [6] reported the antioxidative activity of Spirulina. They found that low levels (2.5-10g/kg diet) of Spirulina supplementation led to an increase in the serum superoxide dismutase and glutathione peroxidase activity. Furthermore, many authors reported that the inclusion of Spirulina in diets influences gut health by reducing the number of *Escherichia coli* and increasing the counts of beneficial lactic acid bacteria (LAB) in ileum and caecum of broilers [6,16]. The fibrous cell wall materials and chlorophylls in the microalgae could provide substrates for the growth of LAB, and so act as prebiotics. Shanmugapriya *et al.* [8] reported that dietary Spirulina inclusion of 10g/kg diet (1%) resulted in a significant increase in the villi height in broilers intestines. Thus, a lower number of pathogenic bacteria and increased villi area is attributed to better nutrient absorption and, consequently higher performances. Contrarily, other studies reported that the addition of this microalgae to broiler diets [2,17] had no effect or had an adverse effect on growth performances. El-Bahr *et al.* [18] found that the inclusion of 1g *S. platensis*/kg diet did not influence FI, FCR or body weight. Altmann *et al.* [17] reported no significant effect on live weight or carcass weight when 50% of the soy protein was replaced by *Arthrospira platensis* in broiler diets. In addition, Pestana *et al.* [19] found lower improvement to BWG and higher FCR in birds fed 150g *S. platensis*/kg feed (15%), individually or in combination with exogenous enzymes, during the finishing period (from 21 to 35 day), while no effect was observed on FI. A possible explanation can be that incorporation of higher amounts of Spirulina into the diet results in protein gelation, increasing digesta viscosity, and lowering amino acid digestibility [20].

These contradictory data between studies could result from several factors: levels of *Arthrospira* used for different broiler hybrids, broiler age, housing conditions, feed preparation, or the way the supplement/feed is administration.

3.2. The effect of Spirulina supplementation on meat quality and meat sensory attributes

The supplementation of different microalgae, including Spirulina, in broiler diets, alters meat quality with regard to consumer expectations of a healthy diet. In different studies, the colour of meat was affected by the addition of Spirulina in broiler feeds. Toyomizu *et al.* [21] reported that Spirulina incorporation in the broiler diet resulted in redder and more yellow meat due to higher pigment content, in particular, due to the accumulation of zeaxanthin. Furthermore, the replacement of 50% of the soy protein in broiler diets with Spirulina influenced both the yellowness and redness of broiler meat [17]. In agreement with such findings, Pestana *et al.* [19] reported that addition of 15% Spirulina with or without enzymes increased the b* value of breast muscle up to three times, and both a* and b* values in thigh muscle. Also, these authors found a significant increase in the total amount of carotenoids. Thus, Spirulina supplementation is a good strategy, not only to manipulate broiler meat colour but also to enrich meat in antioxidants.

From the available literature, it seems that the addition of Spirulina does not significantly influence the pH of the meat [6,19]. In addition, previous studies did not show that Spirulina dietary treatments affect shear force. El-Bahr et al. [18] reported that even low Spirulina levels (1g/kg) in broiler diets significantly decreased drip loss. Similar results were obtained by Athman *et al.* [17], who found a significant increase in cooking loss and storage loss after seven days when Spirulina replaced 50% of the soy protein in broiler diets. Park *et al.* [6] found that the addition of Spirulina (0.25-1%) in broilers diets resulted in a significant reduction of drip loss after seven days of storage. These results are related to the delayed oxidation of the cell membrane caused by antioxidative compounds from Spirulina. Other studies did not report relevant differences in drip loss and cooking loss between the supplemented and control diets [22]. Moreover, *S. platensis* supplementation increased essential amino acid levels (lysine, methionine, tryptophan, histidine, and aspartic acid) in breast muscle. Also, Spirulina inclusion led to significantly lower microbial growth on breast meat, resulting in a longer shelf life of this meat [18].

As far as sensory attributes, Altmann *et al.* [17] reported that meat from Spirulina-fed broilers, after seven days of MAP storage, was less metallic in flavour and more tender than the control. Another study showed that breasts from Spirulina-fed birds scored higher in terms of umami and chicken flavour [22].

Regarding fatty acids, numerous studies confirmed that the addition of Spirulina in feeds increases omega-3 PUFA in meat, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) content, and beneficially affects the n6/n3 ratio. El-Bahr *et al.* [18] found that even low Spirulina supplementation led to a significant increase in the levels of EPA, DHA, n-3 FA, total PUFA, and arachidonic acid in breast meat. Moreover, Bonos *et al.* [2] reported a significant enrichment of polyunsaturated fatty acids in thigh muscle, especially in EPA and DHA, when adding Spirulina into broiler diets. The ultimate nutritional goal is to reach an n6/n3 ratio of 4:1 and a PUFA/SFA ratio above 0.4. Thus, the addition of Spirulina in broiler diets could turn meat into a healthier product for consumers from the fatty acid perspective. Furthermore, and although some studies reported an increase in omega-3 fatty acids, the malondialdehyde levels remained the same or lower [18,2] than in the controls. How the method for including Spirulina in feed affects muscle lipid oxidation is not completely clear and there is lack of information on antioxidant properties related to Spirulina in poultry. Some authors suggest that the phycocyanin is the main component responsible for Spirulina's antioxidant activity, but also highlight the role of carotenoids in cells protection from oxidative stress [23,6]. Contrarily, Altmann *et al.* [22] found increased lipid oxidation levels of meat from broilers fed Spirulina when stored under high oxygen MAP (80% O_2). This higher susceptibility to oxygen should be considered when packing meat from broilers fed Spirulina.

3.3. Spirulina as a sustainable feed ingredient

Spirulina is crop that does not use arable land, involves simple growth requirements and, it is produced through economical and environmentally friendly processes. Its production uses less energy and water per kilogram than proteins from plant sources [24]. Therefore, Spirulina is a sustainable feed alternative with reduced environmental impact. Taking into consideration the rapid and progressive increase of the global population and growing demand for food, Spirulina use, along with other microalgae, in animal feeds could relieve the pressure on agricultural yield for domestic animal feeding [4] and help to preserve the agricultural land for food production for humans. Moreover, Park *et al.* [6] suggested that dietary inclusion of 1% Spirulina powder in broiler diet might reduce ammonia emissions in the excreta.

3.4. Challenges of introducing Spirulina to poultry diets

From a commercial point of view, the application of Spirulina is limited by the high costs of the large-scale production compared to other feeds [3]. To overcome this barrier, developments in low-cost production and drying units and an improvement in operational management are needed [25]. Furthermore, the cost of broiler feed increases with the addition of vitamin-mineral premixes. Venkataraman *et al.* [26] reported that vitamin-mineral premixes can be excluded from broiler diet when

Spirulina is included due to its nutritional composition. Pandav and Puranik [27] confirmed this in a study with *S. platensis* enriched with iron and zinc. Thus, despite the higher price of Spirulina production, by reducing premix costs, this microalgae can be used in broiler nutrition in a cost-effective manner. Other deterrents to the practical use of Spirulina are poor palatability, production costs for the dried powder form and odours [5].

4. Conclusion

Based on the current scientific data, blue-green microalgae, Spirulina, are promising candidates to replace traditional, high protein feed crops, such as soybean meal, the major protein source for broiler feed. Further research should be focused on a deeper understanding of the mechanisms of Spirulina actions, delivery methods, and optimization of the added concentrations in order to achieve maximum beneficial effects for poultry health, productivity, meat product nutritional and organoleptic quality and the environment.

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