Advances in Bioresearch
Adv. Biores., Vol 16 (2) March 2025: 148-157

Print ISSN 0976-4585; Online ISSN 2277-1573
Journal's URL:http://www.soeagra.com/abr.html
CODEN: ABRDC3
DOI: 10.15515/abr.0976-4585.16.2.148157

Advances in Bioresearch

REVIEW ARTICLE

Exploring the Nutritive Value, Composition and Properties of *Spirulina* as a Supplementary Feed for Animal

Swati Sharma and Nisha Rana
Research and Development Cell
Swami Vivekanand Subharti University, Meerut
U.P., India, 250005
Corresponding Author's e-mail: nisharana.zoology@gmail.com and swatisharma.ss9911@gmail.com

ABSTRACT
Spirulina is a microscopic blue-green alga, has significant role as a supplement in the animal feed formulations because of its exceptional nutritive values and beneficial properties. Spirulina is renowned for its rich composition, containing large amounts of vital amino acids, protein, vitamins, minerals, and bioactive substances. Its protein content, often exceeding 60% on the basis of dry weight, makes it valuable resource of highly digestible protein for animals. Moreover, Spirulina is a notable source of lysine, methionine, and cysteine, among other necessary amino acids, crucial for promoting optimal growth and health in various animal species. Beyond its protein content, Spirulina is a potent source of vitamins like vitamins B (B1, B2, B3, B6, & B12), vitamin E, and provitamin A (beta-carotene), which are essential for animals' immune systems and metabolic activities. Additionally, Spirulina is rich in nutrients like iron, calcium, phosphorus, and magnesium, essential for skeletal development, enzymatic activities, and overall physiological functions in animals. The bioactive compounds present in Spirulina, including phycocyanins, chlorophyll, carotenoids, and polysaccharides, contribute to its antioxidant, immunomodulatory and anti-inflammatory qualities. Furthermore, Spirulina exhibits favourable properties as an animal feed supplement, such as high digestibility, palatability, and compatibility with existing feed formulations. Its ability to enhance feed intake, nutrient utilization, and growth performance in various species, including the poultry, fish, and pigs, underscores its potential as a sustainable and cost-effective alternative to conventional feed ingredients. In conclusion, Spirulina emerges as beneficial inclusion in animal feed formulations, offering a potent combination of nutritive value, bioactive compounds, and beneficial properties. Continued research and exploration into its optimal utilization and integration into animal diets hold promise for enhancing animal health, performance, and sustainability in modern livestock production systems.
Keywords: *Spirulina, animal feed, nutritive value, bioactive compounds, growth performance.*

Received 24.12.2024 Revised 21.02.2025 Accepted 25.03.2025

How to cite this article
Swati S and Nisha R. Exploring the Nutritive Value, Composition and Properties of *Spirulina* as a Supplementary Feed for Animal. Adv.Biores. Vol 16 [2] March 2025.148-157

INTRODUCTION

Blue-green algae, often called as cyanobacteria, the first surviving creatures discovered on the Earth. Blue-green algae come in 2 types: edible and harmful. There are edible blue-green algae, including *Spirulina*, *nostac*, and *aphanizonenon*, which have been eaten as a dietary supplement for many hundreds of years. *Spirulina platensis* and *Spirulina maxima* are the species that are most commonly used. Blue-green algae are used in biotechnology as nutrients and feed ingredients in the agriculture sector, in food industry, perfume production, research, and pharmaceutical medicine [60].

All bivalve molluscs, including oysters, scallops, clams, mussels, and juvenile crustaceans and finfish, as well as aquaculture zooplanktons, have been fed microalgae, which are advantageous in aquaculture. For aquatic animals, microalgae provide a good source of vitamins, important fatty acids, minerals, required amino acids, and carotenoid colours [71]. Fish feeding studies have demonstrated that a variety of microalgae may enhance prawns' carotenoid and protein sources, as well as their growth in protein accretion, utilisation in feed, stress response, famine tolerance, physiological activity, disease resistance, and quality of carcass. [46].

The global market for algal products, especially those used in medicines, food and feed supplements, and nutraceuticals, is expected to expand at a 5.8% annual rate between 2017 and 2026, reaching more than USD 53 billion, according to Credence Research Market Analysis [28]. The unhealthy habits of today with the stress, and pollution all want a more nutrient-dense and healthful diet. Then the Superfoods were created for helping to overcome these barriers to a healthy living. This food prevent sickness and so enhance health beyond their nutritional value. *Spirulina*'s scientifically demonstrated health advantages include hypocholesterolemia, antiviral, immunology, and antiglutagenic properties [41]. *Spirulina* is A specific superfood with a high prebiotic content and minerals that promote human health. *Spirulina* has a high content of protein [69].

According to Hironobu *et al.,* (2006), *Spirulina* has recently been linked to immune system change [33]. A range of fish species can benefit from dried algae in terms of growth, feed efficiency, quality of the carcass, and physiological response to disease and stress [46]. Additionally, it has immunomodulatory properties [71]. Fish development, lipid metabolism, composition of the body, and susceptibility to disease may all be significantly impacted by including small quantities of algae into their diet [45]. Red sea bream [45], guppy [18], African sharp tooth catfish [52], and Indian carps all showed faster protein synthesis and somatic growth when fed *S. platensis* [47].

Therefore, *S. platensis* might be beneficial as a nutritious feed additive to encourage fish growth. Numerous research has examined the use of antioxidant nutritional and dietary supplements [21], with a variety of results showing that phenolic compounds can serve as antioxidants in numerous systems of biology in addition to extending the shelf life of food [42].

Many studies which have conducted on the antioxidant capabilities of phenolic compounds in cyanobacteria as well as vegetables and fruits [7, 20, 22, 80, 81]. In 1998, for example, Miranda *et al.,* investigated the antioxidant properties of tocopherols, phenolics, and carotenoids that were isolated from *S. maxima*. They discovered that the organic acids (caffeic, salicylic, synaptic, chlorogenic, quimic, and trans-cinnamic) in the phenolic compounds, either separately or in combination, were responsible for the antioxidant properties of the *S. maxima* extracts [43]. The antioxidant properties of phycocyanin, allophycocyanin, and phycobiliproteins found in *Spirulina* biomass was shown by Estrada *et al.,*[21].

This paper examines the nutritional composition, bioactive properties, and functional benefits of Supplementing animal feed with *Spirulina*. It also explores the effects of *Spirulina* on livestock, poultry, and aquaculture, considering its economic viability and sustainability.

HISTORICAL BACKGROUND OF *Spirulina*

The first discovery was made in 1519 by scientist oft Spanish Hernando Cortez and Conquistadors [59]. *Spirulina* is characterised as blue-green and is an edible cyanobacterium with a spiral structure [8, 26, 30]. Originally grown in the lakes of alkaline water in Africa and Mexico, wild *Spirulina* is now grown commercially and collected all around the world. In the 16th century, the Aztecs collected it from Lake Texcoco in the Valley of Mexico, where it had long been used by prehistoric people as nourishment [59]. Leonard and Compere found spirulina in the 1960s, and since it has become a popular commodity [64,68].

Spirulina is currently cultivated commercially all over the world and utilised as an animal and human nutritional supplement [44]. Fish and animal feed utilise about half of the *Spirulina* produced. *Spirulina* has been produced using high land efficiency since it is commercially cultivated in a liquid media that is rich in nutrients [64]. For instance, *Spirulina* performs better than a number of other conventional animal feed, including barley, wheat, maize, and soybeans, in terms of protein yield land per unit [19, 37].

Additionally, desalinated waste water and animal faeces can be added to the growth substrate to actively develop *Spirulina* [78]. This has been discovered in the faeces of cows [40] and pigs [16], with clearly consistent findings indicating that *Spirulina* is safe to feed to animals. Hasdai and Ben Ghedalia (1981) and Chaiklahan *et al.,* (2010) provide a detailed description of these processes [16, 31]. Nonetheless, this demonstrates *Spirulina* ability to treat wastes cost-effectively and recover all the lost nutrients [62].

MORPHOLOGY OF *Spirulina*

The trichomes of *Spirulina* were filamentous, multicellular, and unbranched. It was called 'trichome' for the filaments. Blue green algae frequently have structures like flagella and heterocysts, however these were absent. The spirals are not cylindrical, but the cells are. The helical form of the filaments and the existence of gas-filled vacuoles in the cells produce floating mats. The cells make dynamic rotational motions.

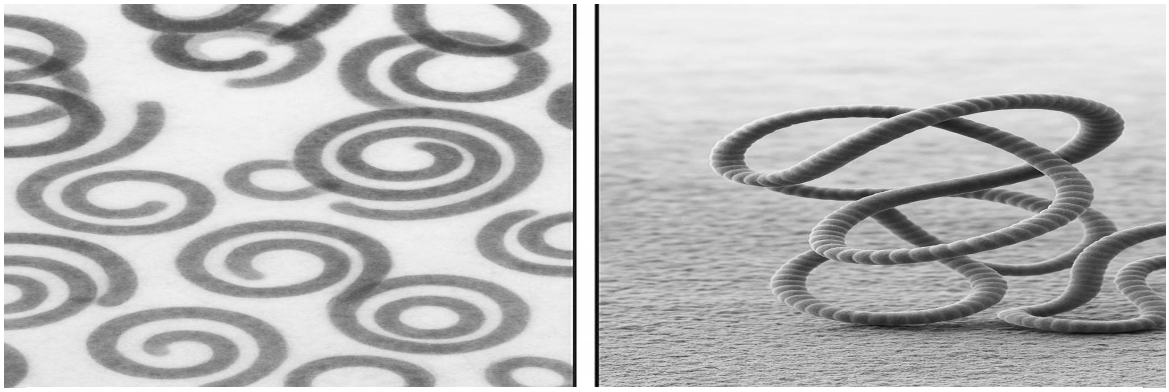

Fig 1: *Spirulina* Morphology. (A) Optical microscopy of axenic *S. platensis*. (B) An axenic *S. platensis* trichome seen in a scanning electron micrograph. {Redrawn from [2]}

The trichome's helical structure is unique to the genus, although even within the same species, the helical parameters varied [67]. Trichomes have a thin sheath around them. They have somewhat or totally diminished apices and noticeable constrictions at the cross-walls. Trichomes exist in a variety of shapes and sizes, ranging from 6 to 12 μm (16 μm) in width [70].

CULTIVATION OF *Spirulina*

Photobiotechnology frequently uses Arthrospira (*Spirulina*) cyanobacteriae, such as *Spirulina platensis,Spirulina pacifica, Spirulina maxima, and Spirulina fusiformis*, to supply protein, essential amino acids, vitamins (particularly B vitamins), β-carotene, and other necessary chemicals. The Aztecs grew *Spirulina* in the saline water, in the Texcoco Lake in 16th century, and today it is known for its outstanding nutritional profile. They dry the captured algae and commercialised it as dehydrated cakes, recognizing for nutritional benefits [58]. *Spirulina* production takes up substantially less space than conventional farming, like poultry and farms of vegetables, ranging from 49 to 132 times less [36].

Spirulina grows best in alkaline conditions (pH 8.5–11), which protects it from bacterial and other microalgal contamination. Of all the species of *Spirulina, Spirulina maxima* and *Spirulina platensis* are the two most significant. About 0.5 mm long trichomes (helixes) are produced by it; they are large enough to allow for simple and economical filtration to separate them from the culture media[15].

Spirulina is cultivated in many different types of states, such as Egypt, France, Germany, Thailand, Japan, Taiwan, India, China, Israel, and the United States. The culture techniques include closed photobioreactors with controlled temperatures and artificial lighting, organic farming in artificial pond, and Sunlight-powered, sophisticated open photobioreactors. Easy biomass harvesting and drying, efficient cell content extraction, and high biological value are just a few benefits of these growth techniques [72].

Another distinguishing criterion is the kind of lighting: solar panels. Solar culture technologies, on the other hand, are deemed viable for long-term large-scale microalgae production. According to Branyikova and Lucakova (2021), the most critical needs for a cultivation system are as follows [15].

1. Proper lighting: Microalgal growth can be inhibited by both too much and too little light. The length of the growth season is influenced by the PBR's placement and design, which control how much light is received and distributed throughout the daytime and year.
2. Sufficient carbon dioxide supply: For the best microalgae growth, atmospheric CO2 levels are too low. The amount of CO2 in the aeration gas can vary from 1 to 100%, depending on the system.
3. By preventing microalgae from settling and forming biofilms, efficient mixing ensures balanced light dispersion and encourages photosynthesis through brief cycles of light and shade.
4. The right building material should be long-lasting, resistant to solar radiation, able to withstand biofilm growth, and appropriate for saline water.
5. Effective oxygen release: By decreasing photosynthetic activity, too much oxygen from photosynthesis can reduce production. Controlling oxygen concentrations is essential.
6. Ideal temperature: Microalgae might be harmed by excessive heat from the sun.
7. Cleaning and operating ease: The PBR should be easy to use and sanitise [65].

NUTRITIONAL COMPOSITION OF *Spirulina*

PROTEIN CONTENT

Numerous investigations on the chemical structure of *S. platensis* and *S. maxima* biomass have found a rather high protein content. Even among microorganisms, only a few bacteria, such Cellulomonas, have

higher protein concentrations than *Spirulina*, which can approach 80% of its dry weight [35]. *Spirulina* is now recognized as the most nutritious food since its protein content is double that of soybeans and across three times that of meat or fish [12].

Spirulina has 50–70% more protein by dry weight than cereals, meat, eggs, soybeans, or dried milk. *Spirulina* proteins are complete, containing all the required amino acids. The essential amino acids isoleucine, valine, and leucine are the most prevalent. When compared to normal alimentary proteins produced from meat, eggs, or milk, it falls short in methionine, cysteine, and lysine but outperforms all plant proteins, including legume proteins [66].

AMINO ACID PROFILE

Spirulina protein has a remarkable amino acid composition. In fact, A number of sufficient amounts of the necessary amino acids available, with the exception of cysteine and lysine, which are considerably less than the standard protein (FAO) [1]. The potential of *Spirulina* as a human protein source has long been acknowledged. While whole powdered milk, wheat germ, soybean flour, peanuts, chicken, Parmesan cheese, fish, and the beef contain 37%, 36%, 36%, 27%, 26%, 24%, 22%, and 22% crude protein, respectively, so does *Spirulina* powder, which has 65–70% crude protein. One important phytochemical included in the high-protein *Spirulina* is C-phycocyanin. Eight essential and eight non-essential amino acids make up protein molecules found in *Spirulina*. As a result, it can serve as the primary cause of protein deficiency [11].

CARBOHYDRATES AND FATTY ACIDS OF *Spirulina*

The absence of cellulose makes the carbohydrates in *Spirulina* easily digested. Additionally, it is a great food supplement for diabetes, obesity, and other conditions because it doesn't contain free sugars [14]. *Spirulina*'s lipid composition, which is rich in polyunsaturated essential fatty acids and devoid of cholesterol, is another benefit. This makes it advantageous for conditions including high blood pressure, obesity, and atherosclerosis. Additionally, *Spirulina* includes gamma linolenic acid (17.43%), myristic acid (0.23%), palmitic acid (46.07), palmitoleic acid (1.26), and oleic acid (5.26), all of which have therapeutic effects [38].

Spirulina has been demonstrated to lower lipid levels since 1981. Later, in 1990, Iwata *et al.,* examined a preclinical investigation using High-fructose diets are used to intentionally cause hyperlipidaemia in wistar rats. For four weeks, the groups received either a high-fructose diet without supplements or a high-fructose diet at concentrations of 5%, 10%, and 15% [34]. Although there was no apparent modification in cholesterol levels or lipoprotein lipase (LPL) between the 5%, 10%, and 15% *Spirulina* concentration groups, the data demonstrated a considerable improvement in the lipid profile with increased LPL activity. Additionally, they showed that a 5% *Spirulina* injection decreased hepatic triacylglycerols [34].

VITAMINS AND MINERALS OF *Spirulina*

The vitamins A, B1, B2, B6, B12, E, and H are all present in good amounts in *Spirulina*. It contains 21 percent of the thiamine and riboflavin RDAs [51]. It has 20 times as much ß-carotene as carrots. It is a beneficial therapeutic diet for anaemia because of its high levels of folic acid and vitamin B12. *Spirulina*'s mineral composition is also appealing. It is rich in magnesium, potassium, and other trace elements, and it has 12 times more iron than any other meal. High in calcium and iron, *Spirulina* is good for bone and tooth health and blood rejuvenation [28].

PIGMENTS AND ANTIOXIDANTS

Spirulina includes a number of bioactive pigments, encompassing phycocyanin, chlorophyll, and carotenoids. Phycocyanin, in particular, has been proven for have anti-inflammatory and antioxidant effects that benefit animal health [13]. The antioxidant ability of these pigments reduces oxidative stress in animals, potentially enhancing overall productivity and health [79].

The compound C-phycocyanin, found in *Spirulina*, has promising anti-cancer properties. According to Manoj *et al.*, the extraction from alcohol of *Spirulina* was shown to be 65% more effective in reducing lipid peroxidation than well-known antioxidants like β-carotene (48%), butylated hydroxy anisol (45%), and tocopherol (35%). Additionally, it has been shown that *Spirulina* water extract has a greater antioxidant impact (76%) than either gallic acid (54%), or chlorogenic acid (56%) [39]. After being isolated from *S. platensis*, Privalov *et al.,* discovered Radachlorin, a new chlorine photosensitiser that, when administered intravenously, caused the tumour to completely shrink [53].Bermejo *et al.,* found that glutathione peroxidase and other cellular antioxidant enzymes are stimulated by phycocyanin [10].

According to Sharma *et al.,* (2007), lipid peroxidation was reduced by elevated levels of these enzymes, which therefore reduced serum transaminase activity. Additionally, lactoperoxidase levels decreased after 40 days of *Spirulina* use [63]. According to certain studies, the special polysaccharides in *Spirulina* boost the activity of enzymes in the cell nucleus and use endonucleases to repair damaged DNA,

preventing the development of tumours in the hamster cheek pouch mucosa [27]. Additionally, Chen *et al.,* (2009) discovered that *Spirulina* enhanced with selenium inhibited the growth of human breast cancer cells MCF-7 [17].

Gad *et al.,* (2011) proposed *Spirulina*'s chelating behaviour, which prevents the formation of ferrozine-Fe2+ complexes via antioxidant chemicals acting as electron donors [23]. *Spirulina* has hepatoprotective properties because it inhibits oxygen stress, which protects against diabetic nephropathy. *Spirulina*'s total antioxidant capacity (TAC) is produced from a variety of phenolic and organic antioxidant compounds that prevent oxidative stress [32].

HEALTH BENEFITS AS AN ANIMAL FEED SUPPLEMENT

ENHANCED GROWTH AND PERFORMANCE

Several studies have found that *Spirulina* supplementation can increase animal growth and feed conversion ratios (FCR). *Spirulina* has been used for enhance body weight in chicken, improve meat quality, and minimise feed intake due to its high nutritional density [76]. *Spirulina* also increases development rates in fish, such as tilapia, by improving protein utilisation and nutritional absorption [47].

IMMUNOMODULATORY EFFECTS

Spirulina's bioactive components, particularly phycocyanin and GLA, have been demonstrated to regulate immunological responses in animals. It has been demonstrated that *Spirulina* increases antibody production and macrophage activity, hence boosting the immune system's overall effectiveness [9]. These immunomodulatory qualities in cattle can lower illness incidence and the requirement for antibiotics, resulting in healthier and more sustainable agricultural methods [61].

IMPROVED GUT HEALTH

Spirulina contains prebiotics, which can improve gut health by stimulating the growth of good bacteria in the gastrointestinal system. *Spirulina* has been proven in poultry research to increase the quantity of beneficial gut microbiota such as Lactobacillus and Bifidobacterium species, hence enhancing nutritional digestibility and immunological responses [73]. Improved gut health is also associated with increased overall growth performance and illness resistance.

ANTIOXIDANT AND ANTI-INFLAMMATORY PROPERTIES

Spirulina is abundant antioxidant content, especially its beta-carotene, vitamin E, and phycocyanin, helps protect animals from oxidative stress [79]. In intensive agricultural settings, where animals are frequently subjected to elevated stress levels that may compromise their immune system and production, this can prove to be very advantageous. Because of *Spirulina* is anti-inflammatory qualities, chronic inflammation's detrimental effects are lessened, enhancing both performance and health.

Spirulina IN DIFFERENT ANIMAL FARMING SYSTEMS

IN POULTRY

Neumann *et al.,* investigated the gradual addition of *Spirulina* to broiler diets through a series of feed experiments. They were able to completely replace soybean meal with diets supplemented to fulfil amino acid needs. Numerous studies have demonstrated that it is possible to successfully substation and incorporate *Spirulina* without negatively affecting animal growth [48, 5074, 75]. However, when animal diets containing It failed to balance according with the requirements for amino acids, reduce live weights and dropped feed intake were noted [74].

Next, the effect of using *Spirulina* as a feed on the final meat's quality was investigated. From the beginning, Altmann *et al.,* (2018) employed a variety of physicochemical traits and sensory analysis to track the nutritional status of meat [3,5]. The grade of the meat varied noticeably among the chicks fed *Spirulina*. In line with other studies, Altmann *et al.,* discovered that meat produced using *Spirulina* as feed for animals had a more vibrant shade [73, 77]; According to the CIELAB colour program, the meat from the breast and thighs has more red (a*) and yellow (b*) colours[3,5].

Spirulina, when added to chicken feed at high concentrations, causes the flesh to become a deep orange shade. Investigations investigating the implications for marketability were carried out in response to this discovery. Customers would not be purchasing poultry meat which is prepared with *Spirulina* until they are given detail defining its odd shade, according to research, Customers are particular about how poultry meat looks [6]. The following were some less drastic changes to the quality of the meat: boosted umami and decreased off-taste in the production of meat utilising *Spirulina* as an feed analysis, improving the flavour of chicken [3,5].

Meat samples fed *Spirulina* showed a higher percentage of lipid oxidation than samples fed other treatments (soybean meal or insect meal), even though *Spirulina* is frequently mentioned as an

antioxidant [29]. This was particularly true when the meat samples were packaged in a modified atmosphere with a high oxygen content [5].

The fatty acid content of the intramuscular fat was also monitored in order to evaluate the quality of the meat. *Spirulina* as a diet did not lead to higher levels of omega-3 fatty acids or polyunsaturated fatty acids (PUFA), particularly gamma-linolenic acid (GLA), as compared to meat samples raised on soybean meal [29]. Even while GLA accounted for around 1% of the identified fatty acids in diets based on *Spirulina*, the cause of the static amounts of GLA is yet unclear. In contrast to soybean meal, PUFA levels did not rise since soybeans also has a significant source of PUFA and levels were constant throughout experimental trials [5].

Future studies have to concentrate on comprehending the physiological absorption of fatty acids generated from *Spirulina*. The effect of feeding *Spirulina* on the initial stages of meat aroma and flavour was also thoroughly examined by Gkarane [25]. In contrast to increasing quantities of chemicals associated to flavour, such as inosine and insosine-50 -monophosphate, *Spirulina* as a feed reduced level of endogenous bioactive compounds, such as anserine, creatine, and carnosine [25]. Additionally, it was found that the fragrance profile of chickens reared on *Spirulina* differed from that of chickens grown on other diets; the profile was partially characterised by compounds associated with lipid oxidation [24].

Spirulina may be successfully added to chicken diets, as these studies above demonstrate. As a source of protein, *Spirulina* alone is insufficient for poultry because of their requirements for certain amino acids; amino acid supplements are needed. This has an impact on applicability to low-input or organic rearing techniques. Moreover, supplementing meat with *Spirulina* has a subjectively favourable impact on meat quality (more taste compounds, detectable flavour, and enhanced colour, for example). The results of this study, however, keep bringing up concerns regarding its capacity to improve the composition of fatty acids and act as an antioxidant.

Spirulina **IN SWINE FEED**

The "Sustainability Transitions" project's research suggests that *Spirulina* is a viable option for swine diets as a protein source. Two studies were conducted on *Spirulina*, First, it was examined from an animal feeding perspective, and then from the aspect of product quality. *Spirulina* can completely substitute soybean meal in livestock diets (with the proper lysine supplementation) without compromising the protein's overall value, according to Neumann [49]. Their trials on feeding barrows and piglets demonstrated this. However, the authors also pointed out that high-amount histidine supplements improve the quality of the protein in pig diets that contain *Spirulina* when combined with lysine, methionine, and threonine [49].

In further experiments, feeding *Spirulina* resulted in somewhat lower carcass weights, however the difference was not insignificant when in contrast to the group that was given soy protein meal. Researchers Altmann et al. (2019) studied barrows fed an advanced diet of 100% *Spirulina* and 9.5% soybean meal. *Spirulina* has little influence on the physico-chemical properties of meat, including lipid oxidation, meat/fat colour, pH, and water-holding capacity. The barrows given *Spirulina* had a slightly lower percentage of monounsaturated fatty acids (MUFA) and a higher percentage of polyunsaturated fatty acids (PUFA) in their back fat compared to the control group[4].

As contrast to the experiment [5], the samples given *Spirulina* also had a larger proportion of GLA [4]. The authors note that the larger proportions of soybean oil in the experimental meals including *Spirulina* might have influenced the results. *Spirulina* in swine feed, according to sensory study, enhanced the overall odour and gave pork loin an astringent aftertaste. The scientists came to the conclusion that *Spirulina* had no detrimental impacts on product quality in spite of these negligible effects. With appropriate amino acid supplementation, both studies—which included several replicates—were strong enough to demonstrate that *Spirulina* can be added in large quantities to swine feed without compromising the quality of the final product or the nutrition of the animals [4].

Spirulina **IN FISH FEED**

Many fish species have already been investigated for using *Spirulina*; nevertheless, in carnivorous fish, high replacement levels frequently result in reduced efficiency in growth and a rise in the percentage of feed conversion[54]. Rosenau looked at how well an experimental diet including *Spirulina* was accepted and performed. *Spirulina* replaced fishmeal in the testing diet, whereas fishmeal constituted a component of the control diet. Numerous genetic lineages of rainbow trout (*Oncorhynchus mykiss*) were used to evaluate the diets; however, the researchers were unable to find any discernible interactions between diet and breed in terms of feed conversion or growth metrics. feeding experiments including brown trout (*Salmo trutta* fario), rainbow trout (*Salvelinus fontinalis*), brook trout (*Salmo trutta* fario), and African catfish (*Clarias gariepinus*) [57].

All species showed a high level of acceptability of the diets overall, Except for brown trout. According to the scientists' theory, the particular species could have refused to eat *Spirulina*. because it didn't like the taste. Both diets had good digestibility, but the feed conversion ratio in rainbow trout and brook trout given *Spirulina*, which led to noticeably slower growth rates across the board for all species [55]. *Spirulina* diet had no effect on the overall microbial community structure, according to a follow-up study of the African catfish intestinal microbiota using 16S rRNA sequencing. However, several bacterial genera showed only minor modifications [56].

Rosenau et al. also examined how *Spirulina* affected the quality of the products. The authors discovered that raw fillet and skin had higher amounts of yellow (b*) and red (a*) colouring, This led to more yellow-orange colouring in the *Spirulina* groups receiving the treatment. The adoption of colour shift by consumers may be significantly impacted. According to preliminary findings from an online customer, fish consumers are not repulsed by the odd colour. In reality, according to Rosenau, in trout fillet, its orange yellow colouring may even be more preferable [56, 57].

These findings contrast with those for chicken eaters and are now being processed for publication [6]. Another important aspect that impacts a product's quality is its fatty acid content, which is greatly influenced by nutrition.SFA (Saturated fatty acids), PUFA, and MUFA in African catfish did not change significantly [55]; nevertheless, PUFA significantly decreased in salmonid fish [57]. Important long-chain PUFA, including docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA), were shown to be lower in the *Spirulina* treatment groups [57].

Findings demonstrate that, the substituting *Spirulina* for fishmeal has benefits for sustainability and even customer preferences. On the other hand, substituting *Spirulina* for fishmeal entirely may have negative effects on animal development and product quality, particularly with regard to food qualities. Furthermore, every fish species and their trophic level have a significant impact on the feasibility of substituting *Spirulina* for fishmeal in fish production and its ramifications. When used as a fish meal, *Spirulina* has less of an effect on fish production in omnivore fish species than in carnivorous fish species.

CONCLUSION

In conclusion, it is known that the filamentous cyanobacterium *Spirulina* contains nutritional and bioactive qualities that make it useful for aquaculture, animal feed, and human consumption. Fish and cattle can benefit greatly from its high protein content, antioxidant qualities, and immune-modulating effects, which can lead to better growth, illness resistance, and feed utilisation. Due to its usage by ancient civilisations and its rediscovery in the 20th century, *Spirulina* has become commercially available worldwide. Its sustainable and economically feasible supplementation comes from its cultivation techniques, which include the utilisation of waste resources.

Spirulina is potential as a superfood and feed additive is increasing due to the growing demand for nutraceuticals. This supports sustainable agriculture practices and nutritional wellness. A cyanobacterium with exceptional nutritional value, *Spirulina* is excellent for crop and animal feed. Its agriculture advantages from sophisticated photobioreactor systems, grows well in alkaline environments, and takes up less room than traditional farming. More protein (50–70% dry weight), important amino acids, vitamins, and minerals may be found in *Spirulina* than in traditional sources such as meat and soybeans. It is perfect for controlling illnesses like diabetes and cardiovascular problems because of its easily digested carbs and cholesterol-free fats.

Spirulina, which is abundant in antioxidants like phycocyanin, has several health advantages for fish, pigs, and poultry alike. It also promotes better development and feed efficiency. It is an important supplement in environmentally friendly animal husbandry systems since it strengthens the immune system, promotes gastrointestinal health, and fights oxidative stress.

REFERENCES

1. Aiello G, Li Y, Boschin G, Bollati C, Arnoldi A, Lammi C (2019). Chemical and biological characterization of *Spirulina* protein hydrolysates: Focus on ACE and DPP-IV activities modulation. J Funct Foods 63:103592.
2. Ali SK, Saleh AM (2012). *Spirulina* - an overview. Int J Pharm Pharm Sci 4(3):9-15.
3. Altmann BA, Neumann C, Velten S, Liebert F, Mörlein D (2018). Meat quality derived from high inclusion of a micro-alga or insect meal as an alternative protein source in poultry diets: A pilot study. Foods 7:34.
4. Altmann BA, Neumann C, Rothstein S, Liebert F, Mörlein D (2019). Do dietary soy alternatives lead to pork quality improvements or drawbacks? A look into micro-alga and insect protein in swine diets. Meat Sci 153:26-34.
5. Altmann BA, Wigger R, Ciulu M, Mörlein D (2020). The effect of insect or microalga alternative protein feeds on broiler meat quality. J Sci Food Agric 100:4292-4302.

6. Altmann BA, Anders S, Risius A, Mörlein D (2022). Information effects on consumer preferences for alternative animal feedstuffs. Food Policy 106:102192.
7. Amaral DM, Moreira M, Lobato MA, Abreu SM (1995). Inhibitory effect of antioxidant substances found in red wine on experimental atherogenesis in rabbits. Vittalle 7:17-24.
8. Becker EW (2007). Micro-algae as a source of protein. Biotechnol Adv 25:207-210.
9. Belay A (2008). *Spirulina* (Arthrospira): Production and quality assurance. In: Handbook of Microalgal Culture. John Wiley & Sons, pp. 339-358.
10. Bermejo-Bescós P, Piñero-Estrada E, del Fresno ÁMV (2008). Neuroprotection by *Spirulina* platensis protean extract and phycocyanin against iron-induced toxicity in SH-SY5Y neuroblastoma cells. Toxicol In Vitro 22(6):1496-1502. https://doi.org/10.1016/j.tiv.2008.05.004
11. Benelhadj S, Gharsallaoui A, Degraeve P, Attia H, Ghorbel D (2016). Effect of pH on the functional properties of Arthrospira (*Spirulina*) platensis protein isolate. Food Chem 194:1056-1063. https://doi.org/10.1016/j.foodchem.2015.08.133
12. Bensehaila S, Doumandji A, Boutekrabt L, Manafikhi H, Peluso II, Bensehaila K, Kouache A, Bensehaila A (2015). The nutritional quality of *Spirulina* platensis of Tamenrasset, Algeria. Afr J Biotechnol 14(19):1649-1654.
13. Bhat VB, Madyastha KM (2001). Scavenging of peroxynitrite by phycocyanin from *Spirulina* platensis: Protection against oxidative damage to DNA. BiochemBiophys Res Commun 285(2):262-266.
14. Braga VS, Mastrantonio DJS, Costa JAV, Morais MG (2018). Cultivation strategy to stimulate high carbohydrate content in *Spirulina* biomass. BioresourTechnol 269:221-226. https://doi.org/10.1016/j.biortech.2018.08.105
15. Branyikova I, Lucakova S (2021). Technical and physiological aspects of microalgae cultivation and productivity—*Spirulina* as a promising and feasible choice. Org Agric 11:269-276.
16. Chaiklahan R, Chirasuwan N, Siangdung W, Paithoonrangsarid K, Bunnag B (2010). Cultivation of *Spirulina* platensis using pig wastewater in a semi-continuous process. J MicrobiolBiotechnol 20:609-614.
17. Chen T, Wong YS, Zheng W (2009). WITHDRAWN: Induction of G1 cell cycle arrest and mitochondria-mediated apoptosis in MCF-7 human breast carcinoma cells by selenium-enriched *Spirulina* extract. Biomed Pharmacother. https://doi.org/10.1016/j.biopha.2009.09.006
18. Dernekbasi S, Una H, Karayucel I, Aral O (2010). Effect of dietary supplementation of different rates of *Spirulina* (*Spirulina* platensis) on growth and feed conversion in guppy (Poecilia reticulata Peters, 1860). J Anim Vet Adv 9:1395-1399.
19. Dismukes GC, Carrieri D, Bennette N, Ananyev GM, Posewitz MC (2008). Aquatic phototrophs: efficient alternatives to land-based crops for biofuels. Curr OpinBiotechnol 19:235-240.
20. Duval B, Shetty K (2001). The stimulation of phenolics and antioxidant activity in pea (Pisum sativum) elicited by genetically transformed anise root extract. J Food Biochem 25:361-377.
21. Estrada JE, Bescós P, Villar Del Fresno AM (2001). Antioxidant activity of different fractions of *Spirulina* platensis protean extract. Il Farmaco 56:497-500.
22. Frankel EN, Waterhouse AL, Teisseche LP (1995). Principal phenolic phytochemicals in selected California wines and their antioxidant activity in inhibiting oxidation of human low-density lipoproteins. J Food Chem 43:890-894.
23. Gad AS, Khadrawy YA, El-Nekeety AA, Mohamed SR, Hassan NS, Abdel-Wahhab MA (2011). Antioxidant activity and hepatoprotective effects of whey protein and *Spirulina* in rats. Nutrition 27(5):582-589. https://doi.org/10.1016/j.nut.2010.04.002
24. Gkarane V, Ciulu M, Altmann BA, Schmitt AO, Mörlein D (2020a). The effect of algae or insect supplementation as alternative protein sources on the volatile profile of chicken meat. Foods 9:1235.
25. Gkarane V, Ciulu M, Altmann BA, Mörlein D (2020b). Effect of alternative protein feeds on the content of selected endogenous bioactive and flavour-related compounds in chicken breast meat. Foods 9:392.
26. Gouveia L, Batista AP, Sousa I, Raymundo A, Bandarra NM (2008). Microalgae in novel food products. In: Papadopoulos KN (ed.), Food Chemistry Research Developments. Nova Science Publishers, New York, pp. 1-37.
27. Grawish ME (2008). Effects of *Spirulina* platensis extract on Syrian hamster cheek pouch mucosa painted with 7,12-dimethylbenz[a]anthracene. Oral Oncol 44(10):956-962. https://doi.org/10.1016/j.oraloncology.2007.11.014
28. Grosshagauer S, Kraemer K, Somoza V (2020). The True Value of *Spirulina*. J Agric Food Chem 68(14):4109-4115. https://doi.org/10.1021/acs.jafc.9b08251
29. Gutiérrez-Salmeán G, Fabila-Castillo L, Chamorro-Cevallos G (2015). Nutritional and toxicological aspects of *Spirulina* (Arthrospira). Nutr Hosp 32:34-40.
30. Gupta R, Bhadauriya P, Chauhan VS, Bisen PS (2008). Impact of UV-B radiation on thylakoid membrane and fatty acid profile of *Spirulina* platensis. Curr Microbiol 56:156-161.
31. Hasdai A, Ben Ghedalia D (1981). Sewage-grown algae as a source of supplementary nitrogen for ruminants. J Agric Sci 97:533-537.
32. Hetta M, Mahmoud R, El-Senousy W, Ibrahim M, El-Taweel G, Ali G (2014). Antiviral and antimicrobial activities of *Spirulina* platensis. World J Pharm Pharm Sci 3:31-39.
33. Hironobu W, Kazuki O, Asmi C, Tassakka T, Masahiro S (2006). Immunostimulant effects of dietary *Spirulina* platensis on carp, Cyprinus carpio. Aquaculture 258:157-163.
34. Iwata K, Inayama T, Kato T (1990). Effects of *Spirulina* platensis on plasma lipoprotein lipase activity in fructose-induced hyperlipidemic rats. J Nutr Sci Vitaminol 36(2):165-171. https://doi.org/10.3177/jnsv.36.165

35. Kameshwari V, Selvaraj S, Sundaramoorthy S (2020). Single Cell Protein *Spirulina*-A Nutrient Treasure. Res J Pharm Pharmacol 12(2):49. https://doi.org/10.5958/2321-5836.2020.00010.5
36. Khoo KS, Chew KW, Yew GY, Leong WH, Chai YH, Show PL, Chen WH (2020). Recent advances in downstream processing of microalgae lipid recovery for biofuel production. BioresourTechnol 304:122996.
37. Kulpys J, Paulauskas E, Pilipavicius V, Stankevicius R (2009). Influence of cyanobacteria Arthrospira (*Spirulina*) platensis biomass additive towards the body condition of lactation cows and biochemical milk indexes. Agron Res 7:823–835.
38. Li TT, Tong AJ, Liu YY, Huang ZR, Wan XZ, Pan YY, Zhao C (2019). Polyunsaturated fatty acids from microalgae *Spirulina* platensis modulates lipid metabolism disorders and gut microbiota in high-fat diet rats. Food Chem Toxicol 131:110558. https://doi.org/10.1016/j.fct.2019.06.005
39. Manoj G, Venkataraman LV, Srinivas L (1992). In ETTA National Symposium on *Spirulina*, (Sheshadri CV, Jeejibai N, Eds.), MCRC Publishers, pp. 148-154.
40. Mitchell SA, Richmond A (1988). Optimization of a growth medium for *Spirulina* based on cattle waste. Biol Wastes 25:41–50.
41. McCarty MF (2007). Clinical potential of *Spirulina* as a source of phycocyanobilin. J Med Food 10(4):566-570. https://10.1089/jmf.2007.621
42. Milié BL, Djilas SM, Canadavnovié-Brunet JM (1998). Antioxidative activity of phenolic compounds on the metal-ion breakdown of lipid peroxidation system. Food Chem 61:443-447.
43. Miranda MS, Cintra RG, Barros SBM, Filho JM (1998). Antioxidant activity of the microalga *Spirulina* maxima. Braz J Med Biol Res 31:1075-1079.
44. Muhling M, Belay A, Whitton BA (2005). Variation in fatty acid composition of Arthrospira (*Spirulina*) strains. J Appl Phycol 17:137–146.
45. Mustafa MG, Takeda T, Umino T, Wakamatsu S, Nakagawa H (1994). Effects of Ascophyllum and *Spirulina* meal as feed additives on growth performance and feed utilization of red sea bream, Pagrus major. J Fac Appl Biol Sci Hiroshima Univ 33:125–132.
46. Mustafa MG, Nakagawa YH (1995). A review: Dietary benefits of algae as an additive in fish feed. Isr J Aquacult 47:155-162.
47. Nandeesha MC, Gangadhara B, Varghese TJ, Keshavanath P (2001). Growth performance of two Indian major carps, catla (Catlacatla) and rohu (Labeo rohita), fed with *Spirulina* platensis. Aquac Res 32(11):867-872.
48. Neumann C, Velten S, Liebert F (2017). Improving the dietary protein quality by amino acid fortification with a high inclusion level of microalgae (*Spirulina* platensis) or insect meal (Hermetiaillucens) in meat-type chicken diets. Open J Anim Sci 8:12–26.
49. Neumann C, Velten S, Liebert FN (2018a). Balance studies emphasize the superior protein quality of pig diets at high inclusion level of algae meal (*Spirulina* platensis) or insect meal (Hermetiaillucens) when adequate amino acid supplementation is ensured. Animals 8:172.
50. Neumann C, Velten S, Liebert F (2018b). The graded inclusion of algae (*Spirulina* platensis) or insect (Hermetiaillucens) meal as a soybean meal substitute in meat-type chicken diets impacts on growth, nutrient deposition, and dietary protein quality depending on the extent of amino acid supple. Open J Anim Sci 8:163–183.
51. Nowruzi B, Haghighat S, Fahimi H, Mohammadi E (2018). Nostoc cyanobacteria species: a new and rich source of novel bioactive compounds with pharmaceutical potential. J Pharm Health Serv Res 9(1):5–12. https://doi.org/10.1111/jphs.12202
52. Promya J, Chitmanat C (2011). The effects of *Spirulina* platensis and Cladophora algae on the growth performance, meat quality and immunity-stimulating capacity of the African sharp-tooth catfish (Clarias gariepinus). Int J Agric Biol 13:77–82.
53. Privalov VA, Lappa AV, Seliverstov OV, Faizrakhmanov AB, Yarovoy NN, Kochneva EV, Kemov YV (2002). Clinical trials of a new chlorin photosensitizer for photodynamic therapy of malignant tumors. In: Optical Methods for Tumor Treatment and Detection: Mechanisms and Techniques in Photodynamic Therapy XI, Vol. 4612, pp. 178-189. SPIE. https://doi.org/10.1117/12.469355
54. Ragaza JA, Hossain MS, Meiler KA, Velasquez SF, Kumar V (2020). A review on *Spirulina*: Alternative media for cultivation and nutritive value as an aquafeed. Rev Aquac 12:2371–2395.
55. Rosenau S, Oertel E, Mott AC, Tetens J (2021a). The effect of a total fishmeal replacement by Arthrospira platensis on the microbiome of African catfish (*Clarias gariepinus*). Life 11:558.
56. Rosenau S, Oertel E, Dietz C, Wessels S, Tetens J, Mörlein D, Ciulu M (2021b). Total replacement of fishmeal by *Spirulina* (Arthrospira platensis) and its effect on growth performance and product quality of African catfish (*Clarias gariepinus*). Sustainability 13:8726.
57. Rosenau S, Ciulu M, Reimer C, Mott AC, Tetens J, Mörlein D (2022). Feeding green: *Spirulina* (*Arthrospira platensis*) induced changes in production performance and quality of three salmonid fish species. Aquac Res (under review).
58. Sánchez AS, Nogueira IBR, Kalid RA (2015). Uses of the reject brine from inland desalination for fish farming, *Spirulina* cultivation, and irrigation of forage shrub and crops. Desalination 364:96–107.
59. Sasson A (1997). Micro Biotechnologies: Recent Developments and Prospects for Developing Countries. BIOTEC Publication, Place de Fontenoy, Paris, France. United Nations Educational, Scientific and Cultural Organization (UNESCO), pp. 11–31.

60. Saranraj P, Sivasakthi S (2014). *Spirulina* platensis–food for future: a review. Asian J Pharm Sci Technol 4(1):26-33.
61. Sarker PK, Kapuscinski AR, Lanois AJ (2016). Towards sustainable aquafeeds: Evaluating the performance of fishmeal-free diets fed to Nile tilapia (Oreochromis niloticus) using *Spirulina* platensis and soybean meal as protein sources. Aquac Res 47(11):3586-3596.
62. Saxena PN, Ahmad MR, Shyam R, Amla DV (1983). Cultivation of *Spirulina* in sewage for poultry feed. Experientia 39:1077–1083.
63. Sharma MK, Sharma A, Kumar A, Kumar M (2007). *Spirulina* fusiformis provides protection against mercuric chloride-induced oxidative stress in Swiss albino mice. Food Chem Toxicol 45(12):2412-2419. https://doi.org/10.1016/j.fct.2007.06.023
64. Shimamatsu H (2004). Mass production of *Spirulina*, an edible microalga. Hydrobiologia 512:39–44.
65. Singh RN, Sharma S (2012). Development of suitable photobioreactor for algae production—A review. Renew Sustain Energy Rev 16:2347–2353.
66. Sotiroudis T, Sotiroudis G (2013). Health aspects of *Spirulina* (Arthrospira) microalga food supplement. J Serb Chem Soc 78(3):395-405.
67. Somasekaran T (1987). Technology of Production of B.G.A. *Spirulina* platensis and its application. CFTRI, Mysore, pp. 150-170.
68. Spolaore P, Joannis-Cassan C, Duran E, Isambert A (2006). Commercial applications of microalgae. J BiosciBioeng 101:87–96.
69. Srilakshmi B (2001). Food Sci. New Age International Limited Publishers, Balachandran.
70. Sow S, Ranjan S (2021). Cultivation of *Spirulina*: An innovative approach to boost up agricultural productivity. Pharma Innov 10(3):799-813. https://doi.org/10.22271/tpi.2021.v10.i3k.5889
71. Takeuchi TJ, Lu G, Yoshizaki Y, Satoh S (2002). Effect on the growth and body composition of juvenile tilapia Oreochromis niloticus fed raw *Spirulina* platensis. Fish Sci 68:34-40.
72. Tambiev AK, Vasilieva SG, Lukyanov AA (2011). Manifestation of salt tolerance of *Spirulina* platensis and *Spirulina* maxima cyanobacteria of the genus Arthrospira (*Spirulina*). Biol Sci 66:133–137.
73. Toyomizu M, Sato K, Taroda H, Kato T, Akiba Y (2001). Effects of dietary *Spirulina* on meat colour in muscle of broiler chickens. Br Poult Sci 42:197–202.
74. Velten S, Neumann C, Bleyer M, Gruber-Dujardin E, Hanuszewska M, Przybylska-Gornowicz B, Liebert F (2018a). Effects of 50 percent substitution of soybean meal by alternative proteins from Hermetiaillucens or *Spirulina* platensis in meat-type chicken diets with graded amino acid supply. Open J Anim Sci 8:119–136.
75. Velten S, Neumann C, Schäfer J, Liebert F (2018b). Effects of the partial replacement of soybean meal by insect or algae meal in chicken diets with graded amino acid supply on parameters of gut microbiology and dietary protein quality. Open J Anim Sci 8:259–279.
76. Venkataraman LV, Somasekaran T, Becker EW (1994a). Replacement value of blue-green alga (*Spirulina* platensis) for fishmeal and a vitamin-mineral premix for broiler chicks. Br Poult Sci 35:373–381.
77. Venkataraman LV, Becker EW, Scheldeman P (1994b). *Spirulina* platensis (Arthrospira): Physiology, cell-biology, and biotechnology. Taylor & Francis.
78. Volkmann H, Imianovsky U, Oliveira JLB, Sant'Anna ES (2008). Cultivation of Arthrospira (*Spirulina*) platensis in desalinator wastewater and salinated synthetic medium: protein content and amino acid profile. 39:98–101.
79. Wu Q, Liu L, Miron A, Klímová B, Wan D, Kuca K (2016). The antioxidant, immunomodulatory, and anti-inflammatory activities of *Spirulina*: An overview. Arch Toxicol 90(8):1817-1840.
80. Yen GC, Chen HY (1995). Antioxidant activity of various tea extracts in relation to their antimutagenicity. J Agric Food Chem 43:27-32.
81. Yoshino M, Murakami K (1995). Interaction of iron with polyphenolic compounds: application to antioxidant characterization. Anal Biochem 257:40-44.