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The Blue-Green Microalga (*Spirulina*) in the Fishery: A Mini Review

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ABSTRACT

Over the past years, *Spirulina* has gained popularity owing to its nutritional profile and bioactive ingredients. The advantages of employing *Spirulina* in aquafeeds as a feed ingredient or as a feed supplement to enhance fish performance in terms of growth and health have been extensively studied. *Spirulina* has an elevated protein content compared to plant sources of protein used in feed. As a result, it can be utilized as a substitute protein source in fish feed. In addition, *Spirulina* contains a wide variety of bioactive ingredients with potential antioxidant, antimicrobial, anti-inflammatory and immunomodulatory activities. The present "Mini Review" emphasizes the significance of microalga use as a replacement for traditional aquafeed ingredients. The review also discusses how microalga-based feed additives have enormous prospects to enhance fish health, illness resistance and productivity. An overview of several pertinent studies on the usage of *Spirulina* in aquafeed and the ideal replacement level in fish diets is provided. All of the studies reviewed in the present work support the use of *Spirulina* as a viable nutritional supplement and a superior alternative protein source in fish feed, with several benefits. *Spirulina* integration with aquaculture systems appears to be a fantastic integrated fish-rearing approach. Future research could focus on examining the trade-offs associated with adding *Spirulina* to aquafeed, with a focus on sustainability analysis, product processing and acceptance.

INTRODUCTION

Microalgae are attracting scientists' attention as they are rising rapidly as ecofriendly and green sources for several applications. Microalgae applications are widely spread in food, cosmetics, pharmaceuticals, fertilizers, water purifiers and animal feed **(Park *et al.*, 2018; Alwaleed *et al.*, 2021)**. Microalgae may be found in both saltwater and freshwater, and they have more effective photosynthetic systems than land-based plants, resulting in higher biomass production **(Davani *et al.*, 2022)**. Microalgae have a tremendous genetic diversity with more than 20000 species **(Wong *et al.*, 2022)**. *Spirulina* is the most farmed photosynthetic prokaryote among the roughly 25,000 microalgal species already discovered, with output estimates of 56,000 tons **(Newton *et al*., 2022)**.

Spirulina is a tiny undifferentiated filamentous, spiral-shaped cyanobacterium that can spontaneously develop in alkaline environments and double its biomass every 2-5 days **(Ayidh AlThobaiti, 2023)**. It contains a wealth of nutrients, including important amino acids, high-quality proteins, carbs, fats, vitamins and colored pigments. This microalga has gained popularity as a fantastic source of commercially accessible bioactive chemicals with antibacterial, antioxidant, anti-inflammatory, immunomodulatory and anti-cancerogenic properties **(Karimzadeh, 2022)**.

Fish are a significant source of dietary protein for humans, accounting for around 20% of the average per capita animal protein consumption for more than 3.1 billion people. Given that capture fisheries possess a largely consistent percentage of fish production, the only way to meet the growing demand for fish is to increase aquaculture production, of which 102 million (tons) are anticipated to be produced by 2025. However, scientists foresee a drop in the yearly growth rate and quality of fish in the aquaculture output owing to the shortage of clean water and high-quality fish feed **(Zhang *et al*., 2020)**.

Identification of novel feed supplies is thus critical for long-term animal production and profitability. Ideally, the novel feed resource must have a high nutritional content and conversion efficiency capable of optimizing animal product quality, and make optimal use of land and water **(Holman & Malau-Aduli, 2013)**. In order to get industrialized results that are both affordable and effective, value-added feed products must be developed. *Spirulina* has the potential to be a cutting-edge feed additive for nutritional uses, spanning from aquaculture to animal production **(Jin *et al*., 2020)**. The addition of microalgae to animal diets might lessen the requirement for synthetic supplements since they are likewise high in vitamins and minerals **(Fawcett *et al*., 2022)**.

The present review emphasized the potential use of *Spirulina* and its bioactive extracts in fish feed and feed additives. The review summarized some successful studies of using *Spirulina* in feeding trials. Finally, the challenges and prospects for using *Spirulina* in the fish nutrition sector are also highlighted.

***Spirulina* and its habitat**

Spirulina is a blue-green alga in the Family Oscillatoriaceae that looks like a spiral of long thin threads. *Spirulina* is known as a blue-green alga (Cynobacterium) because its cellular structure contains both green (chlorophyll) and blue (phycocyanin) pigments. *Spirulina maxima* and *Spirulina platensis* are the two most prevalent species with the highest nutritional value **(Singh *et al*., 2021)**.

Spirulina is primarily grown in alkaline lakes since it cannot live in other types of environments. *Spirulina*'s growth cycle in natural lakes is typically altered by insufficient nutrient supply. Algal populations expand rapidly and eventually disappear when nutrients run out. When decaying algae release their organic nutrients, a new seasonal cycle begins, which subsequently increases the lakes' nutrient levels **(AlFadhly *et al*., 2022)**. *Spirulina* can thrive in soil, marshes, freshwater, brackish water and alkaline thermal springs in addition to lakes **(Rashad & El-Chaghaby, 2021)**.

Spirulina composition and bioactive constituents

Spirulina is a high-nutritional-value source of protein, vitamins, fats, fibers, minerals, carbohydrates and certain natural pigments **(Rashad *et al*., 2019; Seghiri *et al.*, 2019)**. Table (1) shows the proximate composition of *Spirulina* as reported in several previous studies **(Olvera-Novoa *et al*., 1998; Yucetepe *et al*., 2018)**. Its substantial nutritional content includes high levels of protein (70 %), carotenes (4000 mg/kg), omega-3 and omega-6 polyunsaturated fatty acids, sulfolipids, Gamma linoleic acid (GLA), polysaccharides, glycolipids, and provitamins such as vitamins E, A and B, as well as minerals including calcium, manganese, magnesium, iron, selenium, potassium and zinc **(Matufi & Choopani, 2020)**.

Protein, vitamin B (frequently riboflavin), vital minerals (mainly iron), polyunsaturated fatty acids (PUFA), essential amino acids, carotenoids, minerals, chlorophyll, and a few pigments (allophycocyanin and phycocyanin) are all found in *Spirulina platensis*. Owing to the pigments that are present in it, which have antioxidant qualities, it may scavenge peroxide radicals **(El-Chaghaby *et al*., 2019; Elabd *et al*., 2020)**.

Spirulina in fish feeding

The demand for fish feed grows in tandem with the expansion of aquaculture output. Aquaculture has a tremendous potential to accelerate the trend towards expanding fish culture since it is the industry that delivers animal food at the highest rate of growth. The main restraint on this business is the need for high-quality seed and feed. In high-density aquaculture systems, fish feed often makes up 60–70% of operational costs, with protein sources accounting for 45% of the overall feed cost **(Mohammadiazarm *et al.*, 2021)**.

Fishmeal is a key component of fish feed, which causes challenges such as high production costs and the lack of supply availability owing to overexploitation of fisheries resources and rivalry with people's food or livestock. To solve these issues, researchers must look for alternate protein sources for fish feed composition. Researchers have been drawn to study microalgae as possible sources of alternative protein, and among the microalgae species, high potential exists for the use of *Spirulina* species in the production of fishmeal. **(Hakim *et al.*, 2021)**. The benefits of using *Spirulina* in fish feeding are numerous (Fig. 1).

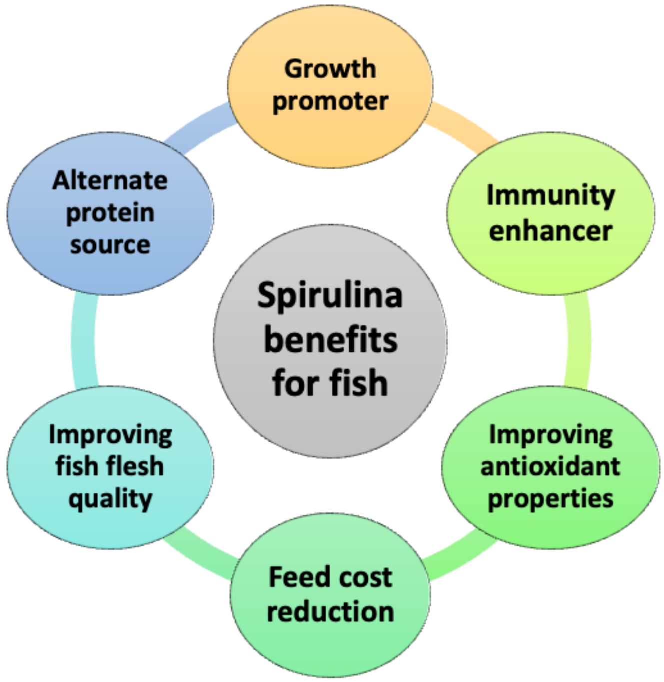

Fig. 1. Benefits of *Spirulina* for fish

When discussing the role of *Spirulina* in aquaculture and fishery nutrition, two paths should be considered **(Rosas *et al.*, 2019)**. *Spirulina* could be either (a) used as a feed ingredient in partial or total replacement of conventional feed ingredients or (b) used as a feed additive for enhancing fish health owing to the bioactive ingredients that *Spirulina* contains. In the next section of this review, these two paths for *Spirulina* use in the fishery will be discussed in brief.

(a) Spirulina as a feed ingredient for fish

Appropriate nutrition has been identified as a vital aspect of fostering standard development and maintaining fish health in aquaculture operations. The introduction of high-quality meals, notably plant and animal- based diets, has greatly aided the tremendous spread of fish farming. In fish farming, feed makes up more than half of all variable operational costs. The protein supply from feed components contributes the most to the prices. This has increased the possibility of using unusual feed components including algae as feed supplies instead of expensive feedstuffs such as fishmeal **(El-Sheekh *et al*. 2014; Mosha, 2019)**.

Several feeding studies have been carried out in order to evaluate the impact of dietary *Spirulina* on the growth performance of different fish species. Table (2) summarizes some successful feeding trials for different fish types.

Table 1. Proximate composition of *Spirulina*

Composition (w/w%)	**Dried basis**
Protein	65.6
Lipid	14.2
Ash	9.5
Carbohydrate	10.7
Crude fibre	1.91
NFE	10.89
Essential amino acids (g/ 100g)	
Arginine	5.22
Histidine	0.99
Isoleucine	3.91
Leucine	5.68
Lysine	3.48
Methionine	1.88
Phenylalanine	3.32
Threonine	3.68
Tryptophan	0.98
Valine	5.10

Table 2. Summarized studies for *Spirulina* used in fish feeding

Fish species	***Spirulina* optimum inclusion level**	**Studied parameters**	**Reference**
The Nile tilapia (*Oreochromis niloticus*)	30% *Spirulina* (*Arthrospira platensis*)	Growth performance, feed utilization efficiency, hepatosomatic and viscerosomatic indices and general health status	**(Velasquez *et al.*, 2016)**
Sabah giant grouper	5% *Spirulina*-enriched diet	Growth performance, intestinal microbial communities	**(Man *et al.*, 2020).**
Oscar fish, *Astronotus ocellatus*	55g/ kg spirulina meal (*Spirulina platensis)*	Growth and feeding parameters, protease activity, protein, fat content, immune-biochemical parameters, blood indices, digestive enzyme activities and overall pigmentation	**(Mohammadiazarm *et al.*, 2021)**

Gangetic mystus *(Mystus cavasius)*	7.5-10% *Spirulina*	Growth parameters, feed utilization and gut microbiota	**(Mamun *et al*., 2023)**
Rainbow trout (*Oncorhynchus mykiss*)	7.5 and 10% *S. platensis*	growth performance, carotenoid concentrations in the skin and fillet, carotenoid deposition	**(Teimouri *et al*., 2013)**
Nile tilapia	1% *Spirulina platensis*	body weight, feed conversion ratio and antioxidant properties	**(Roohani *et al*., 2019).**
Silver rasbora	3% *S. platensis*	sperm performance (Milt volume, sperm concentration, sperm motility, and sperm viability)	**(Putri *et al*., 2020)**
Grass carp	*Spirulina* (up to 5%)	growth performance, antioxidants, digestive enzymes, and innate immune biomarkers	**(Faheem *et al*., 2022)**
Brook trout (*Salvelinus fontinalis*), Rainbow trout (*Oncorhynchus mykiss*), and Brown trout (*Salmo trutta fario*)	Complete replacement of fishmeal with spirulina (*Arthrospira platensis*)	spirulina acceptance, growth and product quality	**(Rosenau and colleagues, 2022)**
Pabda catfish, Ompok pabda	15% *Spirulina platensis*	growth, carcass composition, and amino acid profile of the muscles	**(Akter *et al*., 2023).**
M. cavasius	7.5% and 10% *Spirulina platensis*	growth performance, body composition, feed utilization, and immunological responses	**(Mamun *et al*., 2023)**
Cyprinus carpio	10 mg/kg *Spirulina*	Haematological and biochemical indices, growth performances	**(Ahmed *et al*., 2023)**
Parrot fish	15% *Spirulina platensis*	growth performance, body composition and immune response	**(Kim *et al*., 2013)**
Rainbow trout (*Oncorhynchus mykiss)*	50 and 100 g/ kg *S. platensis*	fatty acid profile, proximate composition, and lipid peroxidation	**(Teimouri *et al*., 2016)**
White shrimp Litopenaeus vannamei	*75% Spirulina platensis*	growth and immunological parameters	**(Macias-Sancho *et al*., 2014)**

According to the study of **Abdulrahman (2013)**, the followings are the principal advantages of using *Spirulina* in aquaculture: 1. Because of *Spirulina*'s intrinsic palatability, growth rates are improved, and less feed is lost. Fish fed with cyanobacterium has reduced belly fat, diverted energy towards development. 2. *Spirulina* given to fish has a higher quality in terms of meat flavor, consistency and color.

(b) Spirulina as a feed additive for fish

Due to their possible harmful effects on aquatic ecosystems downstream, chemicals used in aquaculture farms have sparked environmental concerns, and the need for environmentally friendly safe alternatives is highly requested. *Spirulina*, due to its bioactive properties, could offer such a safer alternative to harmful chemicals used in aquaculture. Over the past years, several researchers have investigated the application of *Spirulina* to alleviate several injurious problems, infections, stresses and diseases in many fish species fish.

Spirulina alleviates aquatic contaminants effects and improves fish health

Heavy metals

When it comes to heavy metals, it is known that their contamination has disastrous consequences on aquaculture, causing reactive oxygen species (ROS) and reactive nitrogen species (RNS), all of which oxidize cell components, including proteins, lipids and DNA. Microalgae which contain a variety of chemicals, including active pigments with antioxidative and anti-inflammatory properties have been proven to alleviate the effects of heavy metals on fish. *Spirulina's* chlorophyll acts as a detoxifier for heavy metals and excess nutrients present in contaminated water **(Alagawany *et al.*, 2021)**.

Bangeppagari (2014) postulated that, *Spirulina'*s metalloprotective function may be ascribed to the presence of β-carotene whose antioxidant mechanism has been proposed to be single oxygen quenching, free radical scavenging, and chain breaking. *Spirulina* also contains a high concentration of vitamins C, E and -carotene, which may prevent lead, cadmium and other heavy metals' toxicity and improve radical scavenging.

Insecticides

Many broad-spectrum insecticides end up in aquatic environments as ultimate receptors, where they undergo a variety of alterations, including physical, chemical and biological changes **(Fadl *et al.*, 2022)**. Recently, experts have been increasingly concerned about the negative impacts of chemical pollutants such as insecticides on aquatic ecosystems and how to combat such toxins using ecologically acceptable medications. There is mounting evidence that several algae species contain high-nutritive-value proteins that may be used not only as a feed supplement for aquatic creatures but also to mitigate the harmful effects of some organic chemicals **(Abdelkhalek *et al*., 2017)**.

Aflatoxins and bacteria

Aflatoxicosis is one of the leading causes of death in fish farms. Dietary functional additives form a friendly strategy that has been linked to positive impacts on aquatic creatures. Microalgae, due to their antioxidant properties, could have a protective effect against aflatoxins negative effects on fish **(Abdel-Daim *et al.*, 2020)**.

In addition, several fish species could be subjected to susceptible pathogenic microorganisms, particularly *Streptococcus* sp., *Aeromonas* sp., *Yersinia* sp. and *Vibrio* sp. Due to increased antibiotic resistance, rising prescription doses, and antibiotic drug side effects, it is vital to seek alternate practices in order to minimize the aforementioned adverse effects and, if feasible, enhance or improve fish output in the aquaculture business **(Adel *et al*., 2016)**. *Spirulina* is thought to have played an important role in avoiding infectious illness by increasing phagocytosis in the blood, and *Spirulina* may have potential application in fish feeds as an antibacterial agent of pharmaceutical relevance **(Güroy *et al*., 2022)**. *Spirulina platensis* has the potential to produce large numbers of antimicrobial substances; therefore, it is considered a suitable candidate for exploitation as a bio-control agent against pathogenic micro-organisms **(Ibrahem *et al*., 2013)**.

Free radicals

Numerous researches have shown that algal extracts are proficient in clearing out free radicals in fish tissues (e.g., liver or gills) and can be utilized as natural antioxidants. By catalyzing the transformation of superoxide anion into molecular oxygen and water, the antioxidant enzymes (superoxide dismutase and catalase) have previously been shown to be present in the fish liver **(Kermani *et al.*, 2020)**. Table (3) depicts a summary of some previously published studies in which *Spirulina* was used as a supplement for fish to alleviate the effect of different contaminants and promote fish health.

Prospectives of *Spirulina* use in aquaculture

Spirulina is employed in aquaculture as a potential replacement for animal-derived proteins in aquafeed. In certain situations, a little addition of *Spirulina* (1-10%) boosted the nutritional content of aquaculture meals, resulting in improved fish growth and health performance. The significant price discrepancies between *Spirulina* and fishmeal are regarded as the principal impediment to the commercial use of S*pirulina* as an aquafeed **(Ragaza *et al*., 2020)**. *Spirulina* is a healthy nutritional supplement that has beneficial impacts on a variety of fish species' development, carcass composition, immunological responses, disease resistance, reproductive efficiency and coloration. *Spirulina* is thus a fantastic prospective replacement for conventional animal-derived proteins in fish diets. Additionally, in aquaculture effluent, spirulina may efficiently absorb nutrients and remove heavy metals. In addition to lowering the charge of the basic components required to grow *Spirulina* that is suitable for use in aquaculture as a food supplement, in high-density fish farms with limited water exchange, this water filtration system also manages the water quality and uses less water. An excellent integrated technique for fish farming appears to be incorporating *Spirulina* into traditional recirculating aquaculture systems **(Zhang *et al*., 2020)**.

Table 3. Some studies involving the use of *Spirulina* as fish feed additive

Fish type	Spirulina reason of use	Reference
The Nile tilapia	Mitigation of sub-acute toxicity of diazinon	**(Abdelkhalek *et al*., 2017)**
Labeo rohita	Decreasing lead acetate toxicity	**(Bangeppagari, 2014)**
The Nile tilapia	Reducing the negative effects fipronil	**(Fadl *et al*., 2022)**
The Nile tilapia	Detoxication of aflatoxin B1	**(Abdel-Daim *et al*., 2020)**
The Nile tilapia	Controlling *Aeromonas veronii* infection	**(Elabd *et al*., 2020)**
The Nile tilapia	Protective role against imidacloprid (IMI) insecticide	**(Abdel-Tawwab *et al*., 2021)**
Juvenile great sturgeon	Mitigation of *Streptococcus iniae* bacterial infection	**(Adel & colleagues, 2016)**
Notopterus notopterus	Reducing iron toxicity	**(Mohanty & Samanta, 2018)**
Rainbow trout	Releasing oxidative stress	**(Kermani *et al*., 2020)**
The Nile tilapia	Protection against *Aeromonas hydrophila* bacterial infection	**(El-Habashi *et al*., 2019)**

CONCLUSION

The present "mini-review" highlighted the use of blue-green microalga *Spirulina* as feed ingredient and additive in aquafeed. Based on the studies collected during the review writing, it was generally agreed that, using spirulina in aquafeed showed promising results though there should be more studies concerning the economic benefits behind its use in large-scale fish production. Future research could focus on analyzing sustainability, product processing and acceptance with a view for better understanding the trade-offs of adding spirulina to aquafeed.

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