



Spirulina: A potent biological catalyst for optimizing weight gain in aquaculture

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Abstract

Historically, animal-derived components like fish meal and fish oil have been the primary protein and lipid ingredients in aquaculture nutrition. However, excessive harvesting has led to a decline in their availability, resulting in significant price hikes. Spirulina has emerged as a superior alternative to other algae like Chlorella due to its high growth potential and efficient carbohydrate synthesis, making it ideal for large-scale cultivation. Consequently, feed manufacturers are now prioritizing Spirulina as a sustainable, plant-based substitute for traditional fish meal to minimize the overhead costs of aquaculture production.

Keywords: Algae, feed, fish, nutrition, protein, quality

Introduction

The worldwide rise in animal protein consumption has triggered a corresponding surge in the demand for feed components. This is particularly evident in the aquaculture sector, which has traditionally leaned on animal-derived proteins, specifically fish meal, as a primary dietary staple. However, the escalating cost and scarcity of fish meal have prompted a scientific shift toward investigating plant-based protein alternatives (Dawood *et al.*, 2020) [6]. Because nutrition accounts for at least 50% of variable overhead in fish farming, maintaining high nutritional standards is vital for delivering affordable, premium products. Based on experimental data using refined ingredients, fish nutritional requirements are defined as the minimum intake necessary to achieve peak physical performance (Hashemi *et al.*, 2008) [14]. These dietary needs are multifaceted, influenced by the species, life stage, environmental conditions, and the presence of natural forage. To support growth and energy in semi-intensive systems, experts recommend a balanced formulation of proteins (such as oilcake and fish meal), carbohydrates (including maize and wheat bran), and essential vitamin-mineral supplements (Hafsa, 2023).

Researchers are increasingly focusing on microalgae, recognizing them as sustainable and environmentally friendly resources for a variety of industries. These organisms are utilized across diverse sectors, including animal nutrition, water treatment, agriculture (fertilizers), cosmetics, pharmaceuticals, and human food production (Park *et al.*, 2018; Alwaleed *et al.*, 2021) [1, 25]. Thriving in both marine and freshwater ecosystems, microalgae possess photosynthetic mechanisms that are significantly more efficient than those of terrestrial plants, leading to superior biomass yields (Davani *et al.*, 2022) [5]. With an immense genetic variety spanning over 20,000 species, this group offers vast potential (Wong *et al.*, 2022) [30]. Among the approximately 25,000 identified species, *Spirulina* stands out as the most widely cultivated, boasting an annual production volume of roughly 56,000 tons (Newton *et al.*, 2022) [23].

Spirulina is a microscopic, spiral-structured, filamentous cyanobacterium known for its ability to flourish naturally in alkaline water, with a rapid growth rate that allows it to double its biomass in just two to five days (Ayidh, 2023) [12]. It serves as a nutritional powerhouse, packed with

essential amino acids, high-value proteins, vitamins, lipids, carbohydrates, and various pigments. Consequently, this microalga has become a premier source of bioactive compounds, valued commercially for their proven anti-inflammatory, antioxidant, antibacterial, anti-cancer, and immunomodulatory effects (Karimzadeh, 2022).

Use of Spirulina in Aquaculture

In the aquaculture sector, *Spirulina* is recognized as a vital dietary component due to its exceptional concentration of proteins, minerals, essential fatty acids, and antioxidant pigments (Nakagawa and Montgomery, 2007) [19]. Specifically, the blue-green algae *Spirulina platensis* (SP) provides a robust nutritional profile for aquafeeds, including high levels of β -carotene and essential amino acids (Zhang *et al.*, 2019) [33]. Its superior protein density and balanced amino acid structure especially when compared to other botanical sources—position it as an ideal substitute for traditional fish meal. Furthermore, while synthetic additives such as astaxanthin and lutein are frequently used (Hanel *et al.*, 2007) [13], natural carotenoid sources like *Spirulina* are also employed to enhance the vivid coloration of ornamental fish (Gouveia and Rema, 2005) [11].

Compared to traditional animal-based feed, *Spirulina* serves as a highly economical alternative. In the Chinese aquaculture sector, it is frequently administered to *Penaeus monodon* (prawns) to stimulate growth and reinforce immune systems. Scallop cultivation also benefits from *Spirulina* supplementation, which leads to faster growth cycles, lower mortality, and increased shell density. Research by Ghaeni (2010) [10] highlighted that this feed improves disease resistance in premium fish species, boosting survival rates by 15–30%. Similarly, *Haliotis midae* (abalone) reached a 37.7% survival rate when utilizing *Spirulina*-based nutrients (Department of Food, 2011) [7]. Its application further extends to the larval stages of green tiger prawns (FAO, 2012) and *Litopenaeus schmitti* (Yoshimatsu and Hossain, 2014) [32]. These advancements in nutrition are vital as the industry expands; however, the massive scale of global fish production continues to pose environmental challenges, particularly regarding high water consumption and the discharge of untreated effluents (FAO, 2012).

Spirulina serves as a cost-effective and environmentally sustainable nutritional source for aquatic species. Research indicates that this microalga is a valuable addition to aquaculture, capable of enhancing the sensory qualities such as flavor, color, and texture of fish meat while acting as a viable protein alternative (Higg *et al.*, 1996; Nakagawa *et al.*, 2007) ^[19]. Within the aqua-feed sector, spirulina is increasingly utilized as a functional dietary supplement or additive, often serving as a substitute for traditional fish meal due to its superior protein profile. While production expenses have historically been a challenge, ongoing advancements in cultivation techniques are optimizing yields and improving economic viability. According to Ragaza *et al.*, (2020) ^[26], the integration of spirulina into aquaculture diets provides multifaceted benefits, including heightened immune response, improved reproductive success, superior growth rates, enhanced stress resilience, and better overall blood health.

In the field of aquaculture, over 40 distinct species of microalgae are currently employed to nourish finfish and shellfish at various developmental stages (Chen, 2003) ^[3]. Among these, *Spirulina* has emerged as a particularly effective dietary component for tropical fish, largely due to its high pigment concentration (Ciferri and Tiboni, 1985) ^[4]. Evidence suggests that *Spirulina* enhances feed palatability; furthermore, fish raised on this diet exhibit reduced abdominal fat, superior meat firmness, improved flavor profiles, and more vibrant skin coloration (Mori, 1987) ^[17]. While beneficial for food fish, it is also highly valued in the ornamental trade, where its phycocyanin content serves to intensify the colors of aquarium species. Traditionally, the industry has relied on fish meal and fish oil as primary nutritional sources, but dwindling supplies and rising costs over the last decade have necessitated a move toward sustainable plant-based alternatives. *Spirulina* represents a viable candidate to reduce the aquaculture industry's dependence on conventional fish meal. Beyond its nutritional profile, *Spirulina* serves a dual purpose by treating wastewater and maintaining water clarity, offering an integrated approach to sustainable fish farming (Zhang *et al.*, 2019) ^[33]. Consequently, these multifaceted benefits are driving feed manufacturers to prioritize *Spirulina* in their formulations.

Spirulina as feed for fishes

Spirulina serves as a viable nutritional alternative to traditional fish meal for a variety of marine and freshwater tropical species. Research by Nandeesh *et al.*, (2001) ^[21] indicates that Indian major carps, such as Rohu (*Labeo rohita*) and Catla (*Catla catla*), can tolerate a complete transition to *Spirulina*-based diets without any detrimental effects. Similarly, Common carp (*Cyprinus carpio*) exhibit not only improved growth but also enhanced digestive enzyme activity (lipase, protease, and amylase) when fish meal is substituted entirely with *Spirulina* (Nandeesh *et al.*, 1998) ^[22].

However, the effectiveness of this substitution varies among other species. While Nile tilapia (*Oreochromis niloticus*) maintains high survival rates at 100% replacement, excessive levels can impair growth rates and alter essential fatty acid profiles (Takeuchi *et al.*, 2002) ^[28]. For Mozambique tilapia (*Oreochromis mossambicus*), the threshold for replacement is approximately 40% before deficiencies in methionine and lysine occur (Olvera *et al.*, 1998). In contrast, red tilapia benefit from a 30% inclusion

rate primarily through enhanced skin pigmentation due to carotenoid content (Ruangsomboon *et al.*, 2010) ^[27]. Rainbow trout reach peak weight gain at a 7.5% inclusion rate (Teimouri *et al.*, 2013) ^[29], while a 10% concentration has been shown to boost hemological markers and protein levels (Yeganeh *et al.*, 2015) ^[31]. Finally, both silver bream and Guppies can safely incorporate *Spirulina* at 50% and 40% levels, respectively, although amino acid limitations prevent higher concentrations in the former (El-Sayed, 1994; Dernekbas *et al.*, 2010) ^[8].

Research indicates that the dietary requirements for spirulina vary between crustacean species. For giant freshwater prawns (*Macrobrachium rosenbergii*), adding 5–10% spirulina to their rations optimizes coloration, survival rates, and overall development (Nakagawa and Gomez-Diaz, 1995) ^[18]. In contrast, Pacific white-leg shrimp (*Litopenaeus vannamei*) can tolerate much higher levels, with spirulina successfully replacing up to 75% of fish meal. However, total replacement of fish meal with spirulina is counterproductive, as it results in a diet deficient in critical amino acids such as threonine, lysine, and arginine (Macias-Sancho *et al.*, 2014) ^[16].

Conclusion

The industrial cultivation of spirulina has established it as a premier dietary additive for both human and animal populations. Its value is rooted in its dense protein concentration, superior amino acid balance, and rich array of essential micronutrients. Within the aquaculture industry, spirulina specifically enhances the growth rates, immune health, and physical coloration of fish and crustaceans. Furthermore, it can replace traditional fish meal either partially or entirely without compromising the welfare of the species. Consequently, spirulina serves as an economically viable and environmentally sustainable protein alternative, outperforming many conventional plant and animal-based feed ingredients.

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