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Exploring the Role of Spirulina in Aquaculture: A Comprehensive Review

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Abstract

Aquaculture plays an important role in meeting the demand of seafood worldwide. *Spirulina platensis*, a blue green algae which is rich in essential nutrients has gained attention for its possible use in preparation of aquafeeds. The nutritional benefits of Spirulina have been extensively studied and it has shown great potential as a dietary supplement in aquaculture to enhance growth and health of the fishes. This review article explores the role of Spirulina in increasing aquaculture production by focusing on its nutritional benefits, its effect on growth performance, health of the fishes and its application in aquaculture.

Keywords: Aquaculture, *Spirulina platensis*, seafood, dietary supplement, blue green algae

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Introduction

In Aquaculture system, natural food only is not sufficient to assist optimum production. Therefore, it is necessary to provide nutritionally balanced diet for promoting optimum aquaculture production. Aquaculture production is impacted by the high feed prices caused by the rising cost of fish meal. In aquaculture, feed cost constitute over half of the total variable operating expenses (National research council, 1993). The cost is mainly due to protein, which is the most expensive feed ingredients and hence, cheaper alternative protein sources would be desirable to cut down on feeding cost. This problem can be solved by including microalgae in fish feed especially spirulina.

Nutritional value of Spirulina has undergone comprehensive evaluation for its potential as a dietary supplement for animal and humans (Belay *et al*; 1996). When compared to fish meal, Spirulina is a cost effective and beneficial source of protein. Spirulina contains important amino acids, minerals, antioxidants, and immune stimulating properties that can reduce the risk and expense of using medication in aquaculture, It has been recognised as a possible sustainable protein alternative compared to fish meal in fish nutrition. (FAO, 2008; Ungsethaphand *et al*., 2009; Onura *et al*.,2022; Al Mamum *et al*.,2022).

As a dietary supplement, it has been demonstrated to have beneficial effect on the growth, reproduction, carcass composition, immune response, and ability to resist diseases in various fishes such as rainbow trout(Oncorhynchus mykiss)(Teimouri *et al*.,2013) common carp (Cyprinus carpio)(Watanuki *et al*.,2006) and nile tilapia (Oreochromis niloticus) (Al - Deriny *et al*.,2020). Studies found that complete replacement of fishmeal with spirulina in some carps showed acceptable performance in zootechnical parameters (Nandeesha *et al*., 1998, 2001; Cao *et al*.,2018). Using Spirulina as fish feed ingredient has led to significant growth performance of cultivated fish (Tongsiri *et al* 2010; Jahan *et al* 2016) and in enhancing the reproductive performance of tilapia by boosting the quantity and size of eggs, as well as their ability to hatch. (Wahbi and Sangak, 2017; Joshua and Zulperi, 2020). Thus spirulina appears to be an ideal fish feed supplement in order to improve development and immune system. Spirulina provides the high nutritive feed material to fishes and aquatic animals which are very low cost and eco-friendly.

General Characters of Spirulina- Spirulina is a multicellular, photosynthetic, filamentous microalga under the genus Arthrospira, the phylum Oscillatoriaceae. It is called blue green algae due to the presence of both green (chlorophyll) and blue (phycocyanin) pigments in its internal structure. Spirulina can be rod or disk shaped and it reproduce by binary fission. It is found in soil, freshwater, sea water, brackish water, marshes and thermal springs. Its body surface is smooth and without covering, making it easily digestible by simple digestive enzymes.

Biochemical Composition- *Spirulina platensis* has a good nutritional profile with high protein content, variety of vitamins, minerals, essential fatty acids, and antioxidant pigments.

Spirulina as Fish Feed Ingredient- Spirulina is a promising fish feed ingredient owing to its high nutritional value and sustainable benefits. Some key points to use Spirulina as fish feed.

NUTRITIONAL BENEFITS – Spirulina has 55-70% protein, vitamins, minerals, fatty acids (gamma -linolenic acid GLA,) essential amino acids,

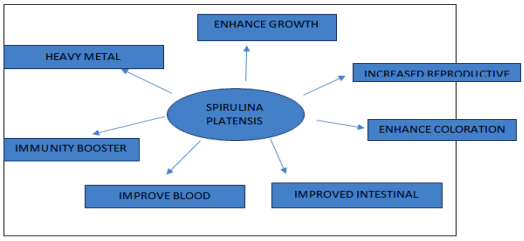
Protein	55-70 % of the dry weight.
Lipids and fatty acids	6-8 % of the dry weight also contains essential fatty acids like linoleic acid, gama linolenic acid, stearidonic acid, eicosepentaenoic acid, docosahexaenoic acid, arachidonic acid.
Vitamins	Vitamin B1, Vitamin B2, Vitamin B3, Vitamin B6, Vitamin B9, Vitamin B12, Vitamin C, Vitamin D and Vitamin E
Minerals	Potassium, Calcium, Chromium, Copper, Iron, Magnesium, Manganese, Phosphorus, Selenium, Sodium and Zinc.
Photosynthetic pigments	Chlorophyll a, xanthophyll, beta carotene, echinenone, myxoxanthophyll, zeaxanthin, also the phycobiliproteins, c-phycocyanin and allophycocyanin.

antioxidants and pigments such as carotenoids. And also, It has an immune stimulating ability, which can reduce the cost and risk of utilizing medication in aquaculture (Amer 2016; Sathasivam *et al* , 2017).

Substitute For Fish Meal - Spirulina has been found to be rich in n-3 LC-PUFA, EPA, and DHA and its protein content is very similar to marine fish meal, which makes it a very suitable alternate for fish meal (Trevi *et al*., 2023). It has been shown that using spirulina as dietary supplement and as a partial substitution in diets have reported enhanced growth performance, meat quality and immune responses of aquaculture species. (Palmegiano *et al* 2008; Adel *et al* 2006; Cao *et al* 2018; Sheikhzadh *et al* 2019; Van *et al* 2020). It was observed in pabda (O. pabda) catfish fingerlings that Spirulina can be used as a source of protein to partially replace fish meal protein with inclusion level upto 15 % without reducing its growth (Akter *et al*., 2023).Spirulina can be used as replacement of fish meal in Rainbow trout due to its protein rich content and no negative effect on the growth performance (Teimouri *et al* 2013).

Easy Digestibilty - In contrast to other types of algae, such as Chlorella, Spirulina does not have cellulose in its cell wall, which is known to reduce digestibility (Olvera -Novoa M *et al*., 1998). Species such as Tilapia have been reported to effectively utilize Spirulina in their diets owing to increase in digestibility and nutrient uptake through gut (Moriarty DJW 1973).

Cost Effectiveness - The cost of fish meal is almost 80% of fish farming industry operating costs where protein is the limiting factor that decides the cost of fish diet. This cost of producing fish feed can be reduced by using an sustainable and environment friendly resource (Datta *et al*., 2011). *Spirulina platensis* seems to be a good and a cost effective source of protein for aquafeed production having a high amount of protein usually between 55 to 70% of the dry matter.



Increased Growth Performance- Assessing growth performance is a crucial parameters to determine the efficacy of feed additives. Parrot fish (Oplegnathus fasciatus) fed with 5% Spirulina shows high weight gain, protein efficiency ratios, feed intake, low feed conversion ratios compared to fish meal control. (kim ss *et al*., 2013). Golden barb (Puntius gelius) showed higher growth rate when 20% fish meal diet is replaced with Spirulina (Hajiahmadian M *et al* 2012). Nile tilapia (O. niloticus) when fed with diet supplemented with 1% spirulina experienced high growth rate, feed conversion rate and average weight gain in weight compared to those fed with control diet (Belal *et al*). It has been verified that 3.38% of dietary *Spirulina platensis* could enhance the growth and immune response of the juvenile gibel carp (Carassius gibelio)(Cao *et al*., 2018).It was recorded that growth performance improved in Hybrid Tilapia after the Spirulina supplementation (Ungsethaphand *et al*., 2010). It was reported in Mekong giant catfish that Spirulina can be used as a dietary supplement at 5 and 10 % of fish meal, these concentrations of spirulina could improve the growth performance, specific growth rate (Tongisiri *et al* 2010). It was observed that 250mg of s.platensis extract resulted in improving growth,FCR and survival rate in juvenile Rainbow trout.(kermani *et al* 2020). The growth performance, feed utilization, whole body proximate composition of stinging catfish improved significantly when the diets with SP 7.5 and SP 10 were fed (Zahan *et al* 2024). Improved final weight, percentage of weight gain and feed utilisation were observed in Oscar fish when it is fed with 54g/kg SP in formulated feed (Mohammadiazarm *et al* 2021). It is shown that growth performance in Red tilapia improved with increase in the S. platensis in the diet upto 75% replacement for fish meal (El-Sheekh *et al* 2014). Fish diet having 7- 10 % of spirulina shows higher growth rate, decreased FCR with higher survival rate (jha *et al* 2018). Replacement of fish meal with 7.5 – 10 % s. platensis in the diet can improve growth performance, body composition, feed utilization in M. cavasius (Al Mamun *et al* 2023). It was observed in Mekong giant Catfish that 5% dried spirulina could be used in replacement of fishmeal and it showed the highest weight gain and average daily gain/day (Tongisiri *et al*.,2010). Studies have shown that 10% inclusion of S. platensis in tilapia diets with 50% replacement of fishmeal improved growth and feed utilization efficiency (AlMulhim *et al*., 2023). Studies shown that total pure *Spirulina platensis* diet is found to have potential effect on growth of Cyprinus carpio (Abbas *et al*., 2020).

Enhance Immune System

Feeding spirulina helped to improve disease resistance of high value fish causing improvement in the survival rates from 15 -30% (Ghaeni,2010). Studies conducted using Spirulina as a supplement and as a partial substitution in the diet have shown that it improve immune response in Mekong giant catfish (Tongsiri *et al* 2010) and African sharp tooth catfish (Promya and chitmanat 2011). Improved immunity has been observed in cultured fish when the fish consume diets containing spirulina (Abdel - tawwab *et al*.,2021, Shalata *et al* 2021, El- Araby *et al* 2022, Al- Mamun *et al* 2023) and including immunological responses of Nile tilapia (o. niloticus) to Aeromonas hydrophila infections (Mabrouk *et al*.,2021). Lower levels of liver and kidney bacteria levels is shown in the treatment group than the control groups, indicating that the spirulina treated carp had high resistance to infection of A. hydrophila (Watanukie *et al*). Supplementation of 2.5 % dietary spirulina had the potential to improve mucosal immune responses and disease resistance of Rainbow trout (Sheikhzadeh *et al*.,2019). It was seen that inclusion of spirulina (10g/Kg) in the diet of O. niloticus showed improved health conditions,enhanced non specific immunity, as well as resistance to P. fluroescens infections.(Ibrahem *et al* 2013). Leukocytes were found to be elevated when fish O .niloticus were fed with 7.5g/Kg of spirulina, lymphocytes and eosinophil concentrations were higher in groups fed with 5.0 and 10g/Kg of Spirulina (Sahan *et al* 2015). It was reported in O.shiranus that administration of spirulina in formulated diet promote immune response against A. hydrophila infection (Siringi *et al* 2016).It is shown that 10% spirulina enhanced immune indexes and digestive enzymes in dwarf gourami (Biabani *et al* 2017). Better immunological responses and improved lysozyme content were observed in stinging catfish when fed with 7.5 SP and 10 SP diets (Zahan *et al* 2024). Oral administration of spirulina in carps leads to enhance phagocytic activities and superoxide anion production by the phagocytic cells (Watanuki *et al* 2006). It was seen that higher basophil concentration was were recorded when c. gariepinus was fed with 1.25g of spirulina diet.(Sayed and Fawzy 2014). Studies shown that using 250 mg/Kg S.platensis methanolic extract can be considered as immunity booster in Rainbow trout (Kermani *et al*.,2020).

Improved Haematological Parameters

Spirulina incorporated diet fed to Oreochromis niloticus showed improved haematological parameters reflecting higher weight gain due to improved health (Moe 2011). (Kapoor and mehta 1992) Reported that spirulina contains a substantial amount of iron and it has significant effects on erythropoiesis increasing RBC counts and haemoglobin concentration. It was observed that Spirulina contains phycocyanin substances that has an effect on fish bone marrow stem cells, which develops RBC and the cellular immune system (Mengumphan and Saengkrachang 2008). It was reported that the fish fed with diet having 5.0-10.0g Spirulina/kg diet showed high RBCs compared to fish fed with control diet (Qureshi and Ali,1996; Savidov,2004). Studies reported that the erythrocytes count was remarkably higher in fish fed with diets supplemented with spirulina compared to control group (Andrews *et al*.,2011). It is observed in oscar fish that fish fed on diet containing 13.75-55 g/kg SP had improved Hb, MCH HCT and MCHC (Mohammadiazarm *et al* 2021). It was reported that diet containing7.5 % spirulina improved haematological parameters, helps in maintaining good health (Javeed *et al* 2021). Red tilapia fed with diet supplemented with S. platensis showed higher RBCs and WBCs (El-Sheekh *et al* 2014). It was seen that RBC, Hb, Hct were higher when Tilapia was fed with 7.5 and 10 g spirulina (Sahan *et al*., 2015). Sayed and Fawzy 2014 reported in clarias gariepinus that fish when fed with spirulina exhibited high RBC's and WBC's as well as haemoglobin value as compared to control group.

Better Coloration

Spirulina is a good source of carotenoids with its high level of xanthophylls, beta carotene and zeaxanthin and significantly affects the pigmentation of fish (Yanar n. Tekelioglu n 1999). Ako *et al* has reported that diet containing 1.5-2% of a carotenoid rich strain of spirulina significantly increased coloration of red velvet sword tail, rainbow fish Pseudomugil furcatus and topaz cichlids Cichlasoma myrnae. It was demonstrated that diets containg 20 % spirulina increased the bluish hue of the female Maylandia lambardoi (Karadal *et al* 2017). In Rainbow trout the blood carotenoid level significantly increased with the increase in the level of dietary S. platensis (Teimouri *et al* 2013). It was observed that Red tilapia when fed with 30 % Spirulina had more carotenoid compared to individuals fed with less Spirulina, indicating that spirulina can be used as a pigment source for incorporation in Red tilapia diets to produce coloration. (Ruangsomboon *et al*.,2010). It was seen that when Spirulina increasing diets were given to Mekong giant catfish it showed increase in pigment and carotenoid content. (Tongisiri *et al* 2010). Ansarifard *et al* 2017 observed that feeding dietary *Spirulina platensis* increased pigmentation in Koi fish (2017). Supplementation of dietary spirulina increased pigmentation in Rainbow trout (Teimouri *et al* 2013). Dietary supplementation of S. platensis increased pigmentation in Oscar fish (Mohammadiazarm *et al* 2021).Dietary supplementation of 6g/Kg spirulina powder in the diet of dwarf gourami was responsible for increased in fin carotenoid concentration (Bakshi *et al* 2018).

Improved Intestinal Health

S. platensis improved the intestinal flora in fish rendering breakdown of indigestible feed components to extract more nutrients from the feed, it also stimulates the production of enzymes that transport fats within the fish for metabolism instead storage (James *et al* 2006). Studies has shown that feed intake decreased and nutrient retention increased by increasing digestive enzyme activities in fish fed with dietary SP (Anarifard *et al* 2018). It has been reported that diets supplemented with SM significantly promote the thickness of the intestinal muscular layer and villi structure in Yellow river carp (Ren *et al* 2022). Studies reported that inclusion of dietary Spirulina in aquatic organisms enhanced the digestion and absorption process significantly (Sheikhzadeh *et al* 2019).

Increased Reproductive Rate- It was concluded that inclusion of spirulina in fish feed enhance the spawning process and quality of fries produced is due to the lipid content of spirulina especially n-6 fatty acids (Mazorra *et al*.,2003). It was also stated that n-6 fatty acids group especially ARA acid improve spawning efficiency and fry morphometric characters (Santiago and Reyes 1993). Spirulina tested on Nile tilapia as a primary feed has shown increase in the egg production, hatching percentage, and the survival rates of fish in comparison with the conventional fish (Promya and Chitmanat 2011). It was reported that feed with 2.5% Spirulina on Cichlid yellow fish (Pseudotro pheusacei) showed the highest egg production and hatching percentage and there was a remarkable difference compared with other treatment (Guroy *et al*.,2012).Using spirulina as a main feed of Nile tilapia caused the enhancement in egg quantity and quality (Lu and Takeuchi 2004). Inclusion of dietary spirulina in nile tilapia during its gonadal development helps improve reproductive performance which leads to high fecundity and GSI values, better quality of eggs and larvae (Wahabi and Sangak 2017). Studies on dwarf gourami shows that 3% spirulina in diet show improved reproductive factors (Biabani *et al* 2017). It was concluded that Poecilia reticulata when fed with diet having spirulina performed breeding 10-15 days earlier as compared to fishes fed with control diet (upreti and kumar 2020).

Heavy Metal Detoxification

Spirulina has a very unique quality of detoxification or to chelate toxic minerals, a characteristic which is not yet confirmed in any other microalgae (Maeda and Sakaguchi, 1990; Okamura and Ayoma, 1994). Spirulina is accounted to alleviate organ toxicity induced by heavy metals like Cadmium, lead (Simsek *et al*.,2009). Spirulina administration has shown to decrease the toxic effects of deltamethrin on O. niloticus caused by the pesticides due to its free radical scavenging and active antioxidant activity (Abdelkhalek *et al*.,2015). supplementation of spirulina in diet caused the reduction of copper

toxicity in C. mrigala and in turn improved the food utilization, phosphatase activity, and haematological parameters (James *et al*., 2009).The supplementation of Spirulina in the diet reduced the mercuric chloride toxicity in labeo rohita and it improved the haematological parameters such as RBC and haemoglobin content as the dose of s. platensis was increased (Shelke and Wani 2015). It was shown that S. platensis provide protection against toxic action of mercury and helped in increasing the blood and enzyme generation (kaoud *et al* 2012).

Conclusion

The present review highlights the use of spirulina as a fish feed ingredients and its potential benefits. It has emerged as a promising dietary supplement in aquaculture offering a sustainable and nutritious feed alternative. It has been shown to improve growth performance, immunity, disease resistance in number of fishes. It also act as an immunomodulator that stimulates fish immune system to fight infections and diseases which can reduce the dependency on antibiotics. Overall Spirulina offers a promising solution for the sustainable and cost effective fish feed production, with numerous benefits for the fish health and aquaculture operations.

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Reference

Ungsethaphand, T., Peerapornpisal, Y., & Whangchai, N. (2009). Production of *Spirulina platensis* using dry chicken manure supplemented with urea and sodium bicarbonate. Maejo Int. J. Sci. Technol. 3,379-387.

Onura, C. N. A., Muthumbi, A. W., James, J. G., & Wang'ondu, V. W. (2022). Stress Tolerance of African Catfish (Clarias gariepinus, Burchell, 1822) Larvae Fed on *Spirulina platensis* or Eisenia fetida in Partial Replacement of Caridina nilotica in Formulated Diets. East African Journal of Agriculture and Biotechnology, 5(1), 195-212.

Al Mamun, M., Hossain, M. A., Saha, J., Khan, S., Akter, T., & Banu, M. R. (2023). Effects of spirulina *Spirulina platensis* meal as a feed additive on growth performance and immunological response of Gangetic mystus Mystus cavasius. Aquaculture Reports, 30:101553.doi:10.1016/j.aqrep.2023.101553

Teimouri, M., Amirkolaie, A. K., & Yeganeh, S. (2013). Effect of *Spirulina platensis* meal as a feed supplement on growth performance and pigmentation of rainbow trout (Oncorhynchus mykiss). World Journal of Fish and Marine Sciences, 5(2), 194-202

Watanuki, H., Ota, K., Tassakka, A. C. M. A., Kato, T., & Sakai, M. (2006). Immunostimulant effects of dietary *Spirulina platensis* on carp, Cyprinus carpio. Aquaculture, 258(1-4), 157-163.

Al-Deriny, S. H., Dawood, M. A., Abou Zaid, A. A., Wael, F., Paray, B. A., Van Doan, H., & Mohamed, R. A. (2020). The synergistic effects of *Spirulina platensis* and Bacillus amyloliquefaciens on the growth performance, intestinal histomorphology, and immune response of Nile tilapia (Oreochromis niloticus). Aquaculture Reports, 17, 100390.

Tongsiri, S., Mang-Amphan, K., & Peerapornpisal, Y. (2010). Effect of replacing fishmeal with Spirulina on growth, carcass composition and pigment of the Mekong giant catfish. Asian Journal of Agricultural Sciences, 2(3), 106-110.

Jahan, T., Ali, M. A., & Rahman, T. (2016). Investigation on the growth performances of selected probiotic supplemented tilapia (Oreochromis niloticus) and walking catfish (Clarias batrachus) fingerlings. Fundamental and Applied Agriculture, 1(2), 75-81.

Wahbi, O. M., & Sangak, Y. (2017). Enhancement of reproductive performance of Nile tilapia Oreochromis niloticus using phytobiotic *Spirulina platensis*. Journal of Biological Sciences, 17(7), 305-311.

Joshua, W. J., & Zulperi, Z. (2020). Effects of *Spirulina platensis* and Chlorella vulgaris on the Immune System and Reproduction of Fish. Pertanika Journal of Tropical Agricultural Science, 43(4),429-444.

Amer, S. A. (2016). Effect of *Spirulina platensis* as feed supplement on growth performance, immune response and antioxidant status of mono-sex Nile Tilapia (Oreochromis niloticus). Benha veterinary medical journal, 30(1), 1-10.

Olvera-Novoa, M. A., Domínguez-Cen, L. J., Olivera-Castillo, L., & Martínez-Palacios, C. A. (1998). Effect of the use of the microalga Spirulina maxima as fish meal replacement in diets for tilapia, Oreochromis mossambicus (Peters), fry. Aquaculture research, 29(10), 709-715.

Moriarty, D. J. W. (1973). The physiology of digestion of blue-green algae in the cichlid fish, Tilapia nilotica. Journal of Zoology, 171(1), 25-39.

Palmegiano, G. B., Gai, F., Daprà, F., Gasco, L., Pazzaglia, M., & Peiretti, P. G. (2008). Effects of Spirulina and plant oil on the growth and lipid traits of white sturgeon (Acipenser transmontanus) fingerlings. Aquaculture research, 39(6), 587-595.

Adel, M., Yeganeh, S., Dadar, M., Sakai, M., & Dawood, M. A. (2016). Effects of dietary *Spirulina platensis* on growth performance, humoral and mucosal immune responses and disease resistance in juvenile great sturgeon (Huso huso Linnaeus, 1754). Fish & Shellfish Immunology, 56, 436-444.

Cao, S., Zhang, P., Zou, T., Fei, S., Han, D., Jin, J., ... & Xie, S. (2018). Replacement of fishmeal by spirulina Arthrospira platensis affects growth, immune related-gene expression in gibel carp (Carassius auratus gibelio var. CAS III), and its challenge against Aeromonas hydrophila infection. Fish & shellfish immunology, 79, 265-273.

Sheikhzadeh, N., Mousavi, S., Hamidian, G., Firouzamandi, M., Oushani, A. K., & Mardani, K. (2019). Role of dietary *Spirulina platensis* in improving mucosal immune responses and disease resistance of rainbow trout (Oncorhynchus mykiss). Aquaculture, 510, 1-8.

Van Vo, B., Siddik, M. A., Fotedar, R., Chaklader, M. R., Hanif, M. A., Foysal, M. J., & Nguyen, H. Q. (2020). Progressive replacement of fishmeal by raw and enzyme-treated alga, *Spirulina platensis* influences growth, intestinal micromorphology and stress response in juvenile barramundi, Lates calcarifer. Aquaculture, 529, 735741.

Kim, S. S., Rahimnejad, S., Kim, K. W., & Lee, K. J. (2013). Partial replacement of fish meal with Spirulina pacifica in diets for parrot fish (Oplegnathus fasciatus). Turkish Journal of Fisheries and Aquatic Sciences, 13(2).197-204

Hajiahmadian, M., Vajargah, M. F., Farsani, H. G., & Chorchi, M. M. (2012). Effect of *Spirulina platensis* meal as feed additive on growth performance and survival rate in golden barb fish, Punius gelius (Hamilton, 1822). Journal of Fisheries International, 7(3-6), 61-64.

Belal, E. B., Khalafalla, M. M. E., & El-Hais, A. M. A. (2012). Use of spirulina (Arthrospira fusiformis) for promoting growth of Nile Tilapia fingerlings. African Journal of Microbiology Research, 6(35), 6423-6431.

Tongsiri, S., Mang-Amphan, K., & Peerapornpisal, Y. (2010). Effect of replacing fishmeal with Spirulina on growth, carcass composition and pigment of the Mekong giant catfish. Asian Journal of Agricultural Sciences, 2(3), 106-110.

Cao, S., Zhang, P., Zou, T., Fei, S., Han, D., Jin, J., ... & Xie, S. (2018). Replacement of fishmeal by spirulina Arthrospira platensis affects growth, immune related-gene expression in gibel carp (Carassius auratus gibelio var. CAS III), and its challenge against Aeromonas hydrophila infection. Fish & shellfish immunology, 79, 265-273.

Ungsethaphand, T., Peerapornpisal, Y., Whangchai, N., & Sardsud, U. (2010). Effect of feeding *Spirulina platensis* on growth and carcass composition of hybrid red tilapia (Oreochromis mossambicus× O. niloticus). Maejo international journal of science and technology, 4(2), 331-336.

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 Sharptooth Catfish (Clarias gariepinus).Int. J. Agric. Biol., 13; 77-82.

Shalata, H. A., Bahattab, O., Zayed, M. M., Farrag, F., Salah, A. S., Al-Awthan, Y. S., ... & Mohamed, R. A. (2021). Synergistic effects of dietary sodium butyrate and *Spirulina platensis* on growth performance, carcass composition, blood health, and intestinal histomorphology of Nile tilapia (Oreochromis niloticus). Aquaculture Reports, 19, 100637.

Abdel-Tawwab, M., El-Saadawy, H. A., El-Belbasi, H. I., Abd El-Hameed, S. A., & Attia, A. A. (2021). Dietary spirulina (Arthrospira platenesis) mitigated the adverse effects of imidacloprid insecticide on the growth performance, haemato-biochemical, antioxidant, and immune responses of Nile tilapia. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 247, 109067.

Al Mamun, M., Hossain, M. A., Saha, J., Khan, S., Akter, T., & Banu, M. R. (2023). Effects of spirulina *Spirulina platensis* meal as a feed additive on growth performance and immunological response of Gangetic mystus Mystus cavasius. Aquaculture Reports, 30, 101553.

El-Araby, D. A., Amer, S. A., Attia, G. A., Osman, A., Fahmy, E. M., Altohamy, D. E., ... & Tolba, S. A. (2022). Dietary *Spirulina platensis* phycocyanin improves growth, tissue histoarchitecture, and immune responses, with modulating immunoexpression of CD3 and CD20 in Nile tilapia, Oreochromis niloticus. Aquaculture, 546, 737413.

Mabrouk, M. M., Ashour, M., Labena, A., Zaki, M. A., Abdelhamid, A. F., Gewaily, M. S., ... & Ayoub, H. F. (2022). Nanoparticles of Arthrospira platensis improves growth, antioxidative and immunological responses of Nile tilapia (Oreochromis niloticus) and its resistance to Aeromonas hydrophila. Aquaculture Research, 53(1), 125-135.

Watanuki, H., Ota, K., Tassakka, A. C. M. A., Kato, T., & Sakai, M. (2006). Immunostimulant effects of dietary *Spirulina platensis* on carp, Cyprinus carpio. Aquaculture, 258(1-4), 157-163.

Sheikhzadeh, N., Mousavi, S., Hamidian, G., Firouzamandi, M., Oushani, A. K., & Mardani, K. (2019). Role of dietary *Spirulina platensis* in improving mucosal immune responses and disease resistance of rainbow trout (Oncorhynchus mykiss). Aquaculture, 510, 1-8.

Mengumphan, K., Saengkrachang, J., (2008). Production of Generation-2 Mekong giant catfish (Pangasinodon gigas) cultured with Spirulina sp. Mj. Int. J. Sci. Tech. 2 (03),559-567.

Qureshi, M. A., & Ali, R. A. (1996). *Spirulina platensis* exposure enhances macrophage phagocytic function in cats. Immunopharmacology and immunotoxicology, 18(3), 457-463.

Savidov, N., & Brooks, A. B. (2004). Evaluation and development of aquaponics production and product market capabilities in Alberta. Brooks, AB, Canada: Crop Diversification Centre South, Alberta Agriculture, Food and Rural Development.

Andrews, S. R., Sahu, N. P., Pal, A. K., Mukherjee, S. C., & Kumar, S. (2011). Yeast extract, brewer's yeast and spirulina in diets for Labeo rohita fingerlings affect haemato-immunological responses and survival following Aeromonas hydrophila challenge. Research in veterinary science, 91(1), 103-109.

Karadal, O., Güroy, D., & Türkmen, G. (2017). Effects of feeding frequency and Spirulina on growth performance, skin coloration and seed production on kenyi cichlids (Maylandia lombardoi). Aquaculture international, 25, 121-134.

Ruangsomboon, S., Choochote, S., & Taveekjakarn, P. (2010). Growth performance and nutritional composition of red tilapia fed diets containing raw Spirulina. The international conference on sustainable community development. Thailand and Vientiane, Lao.

YANAR, M., & TEKELİOĞLU, N. (1999). The effect of natural and synthetic carotenoids on pigmentation of gold fish (Carassius auratus). Turkish Journal of Veterinary & Animal Sciences, 23(9), 501-506.

Tongsiri, S., Mang-Amphan, K., & Peerapornpisal, Y. (2010). Effect of replacing fishmeal with Spirulina on growth, carcass composition and pigment of the Mekong giant catfish. Asian Journal of Agricultural Sciences, 2(3), 106-110.

Ako, H., Tamaru, C. S., Asano, L., Yuen, B., & Yamamoto, M. (2000). Achieving natural coloration in fish under culture. Spawning and maturation of aquatic species. United States-Japan cooperative program in natural resources technical report, (28).

James, R., Sampath, K., Thangarathinam, R., & Vasudevan, I. (2006). Effect of dietary spirulina level on growth, fertility, coloration and leucocyte count in red swordtail, Xiphophorus helleri. Israeli Journal of Aquaculture-Bamidgeh, 58(2): 97-104

Ansarifard, F., Rajabi Islami, H., Shamsaie Mehrjan, M., & Soltani, M. (2018). Effects of Arthrospira platensis on growth, skin color and digestive enzymes of Koi, Cyprinus carpio. Iranian Journal of Fisheries Sciences, 17(2), 381-393.

Ren, H. T., Du, M. X., Zhou, J., & An, H. Y. (2022). Effect of spirulina and ferrous fumarate on intestinal morphology and the diversity of gut microbiota of yellow river carp. Biological Trace Element Research, 1-8.

Sheikhzadeh, N., Mousavi, S., Hamidian, G., Firouzamandi, M., Oushani, A. K., & Mardani, K. (2019). Role of dietary *Spirulina platensis* in improving mucosal immune responses and disease resistance of rainbow trout (Oncorhynchus mykiss). Aquaculture, 510, 1-8.

Mazorra, C., Bruce, M., Bell, J. G., Davie, A., Alorend, E., Jordan, N., ... & Bromage, N. (2003). Dietary lipid enhancement of broodstock reproductive performance and egg and larval quality in Atlantic halibut (Hippoglossus hippoglossus). Aquaculture, 227(1-4), 21-33.

Güroy, B., Şahin, İ., Mantoğlu, S., & Kayalı, S. (2012). Spirulina as a natural carotenoid source on growth, pigmentation and reproductive performance of yellow tail cichlid Pseudotropheus acei. Aquaculture International, 20, 869-878.

Lu, J., & Takeuchi, T. (2004). Spawning and egg quality of the tilapia Oreochromis niloticus fed solely on raw Spirulina throughout three generations. Aquaculture, 234(1-4), 625-640.

Santiago, C. B., & Reyes, O. S. (1993). Effects of dietary lipid source on reproductive performance and tissue lipid levels of Nile tilapia Oreochromis niloticus (Linnaeus) broodstock. Journal of Applied Ichthyology, 9(1), 33-40.

Maeda, S. and Sakaguchi, T (1990). Accumulation and detoxification of toxic metal elements by algae. Introduction to applied phycology., 109-136.

Okamura, H., & Aoyama, I. (1994). Interactive toxic effect and distribution of heavy metals in phytoplankton. Environmental Toxicology and Water Quality, 9(1), 7-15.

James, R., Sampath, K., Nagarajan, R., Vellaisamy, P., & Manikandan, M. M. (2009). Effect of dietary Spirulina on reduction of copper toxicity and improvement of growth, blood parameters and phosphatases activities in carp, Cirrhinus mrigala (Hamilton, 1822). Indian exp.Biology,47:754-759

Simsek, N., Karadeniz, A., Kalkan, Y., Keles, O. N., & Unal, B. (2009). *Spirulina platensis* feeding inhibited the anemia-and leucopenia-induced lead and cadmium in rats. Journal of hazardous materials, 164(2-3), 1304-1309.

Abdelkhalek, N. K., Ghazy, E. W., & Abdel-Daim, M. M. (2015). Pharmacodynamic interaction of *Spirulina platensis* and deltamethrin in freshwater fish Nile tilapia, Oreochromis niloticus: impact on lipid peroxidation and oxidative stress. Environmental Science and Pollution Research, 22, 3023-3031.

AD, S., & Wani, G. P. (2015). Protective effect of dietary supplementation of *Spirulina platensis* on improvement of growth parameters in mercuric chloride exposed fish, Labeo rohita. In National Conference on Advances in Bioscience & Environmental Science: Present & Future (ABES) (p. 37).

Trevi, S., Uren Webster, T., Consuegra, S., & Garcia de Leaniz, C. (2023). Benefits of the microalgae Spirulina and Schizochytrium in fish nutrition: a meta-analysis. Scientific Reports, 13(1), 2208.

Wahbi, O. M., & Sangak, Y. (2017). Enhancement of reproductive performance of Nile tilapia Oreochromis niloticus using phytobiotic *Spirulina platensis*.

Biabani Asrami, M., Sudagar, M., Yousefi Siahkalroodi, S., & Mazandarani, M. (2020). The effect of Spirulina on reproductive parameters, body composition, immune indices and digestive enzyme in dwarf gourami (Trichogaster lalius). Iranian Journal of Fisheries Sciences, 19(3), 1280-1291.

Upreti, U., & Kumar, A. (2020). Effect of dietary Spirulina on the breeding behaviour of Poecilia reticulata. Pharma Innov. J., 366-368.

Ibrahem, M. D., Mohamed, M. F., & Ibrahim, M. A. (2013). The role of *Spirulina platensis* in growth and immunity of nile tilapia and its resistance to bacterial infection. J Agric Sci, 5, 109-117.

Şahan, A., Taşbozan, O., Aydin, F., Özütok, S., Erbaş, C., Duman, S., ... & Özcan, F. (2015). Determination of some haematological and non-specific immune parameters in nile tilapia (Oreochromis niloticus L., 1758) fed with Spirulina (*Spirulina platensis*) added diets. Journal of aquaculture engineering and fisheries research, 1(3), 133-139.

Siringi, J. O., Kang'ombe, J., Jere, W., & Mtethiwa, A. H. (2016). Effect of dietary spirulina supplements on growth, haematological factors and survival of Oreochromis shiranus challenged with Aeromonas hydrophila.

Kermani, P., Babaei, S., Abedian-Kenari, A., & Hedayati, M. (2020). Growth performance, plasma parameters and liver antioxidant enzymes activities of Rainbow trout (Oncorhynchus mykiss) juvenile fed on *Spirulina platensis* extract. Iranian Journal of Fisheries Sciences, 19(3), 1463-1478.

Zahan, N., Hossain, M. A., Islam, M. R., Saha, J., Akter, T., Fatema, U. K., & Haque, F. (2024). Effects of dietary *Spirulina platensis* on growth performance, body composition, haematology, immune response, and gut microflora of stinging catfish Heteropneustes fossilis. Aquaculture Reports, 35, 101997.

Watanuki, H., Ota, K., Tassakka, A. C. M. A., Kato, T., & Sakai, M. (2006). Immunostimulant effects of dietary *Spirulina platensis* on carp, Cyprinus carpio. Aquaculture, 258(1-4), 157-163

Mohammadiazarm, H., Maniat, M., Ghorbanijezeh, K., & Ghotbeddin, N. (2021). Effects of spirulina powder (*Spirulina platensis*) as a dietary additive on Oscar fish, Astronotus ocellatus: Assessing growth performance, body composition, digestive enzyme activity, immune-biochemical parameters, blood indices and total pigmentation. Aquaculture nutrition, 27(1), 252-260.

JHA, G. N., SARMA, D., Akhtar, M. S., Charak, A. S., Paul, N., & Kour, R. (2018). Effect of spirulina (*Spirulina platensis*) fortified diets on growth performance of two important cold water fishes viz. Barilius bendelisis and Schizothorax richardsonii. COLDWATER FISHERIES SOCIETY OF INDIA, 1(1), 85-88.

El-Sheekh, M., El-Shourbagy, I., Shalaby, S., & Hosny, S. (2014). Effect of feeding Arthrospira platensis (Spirulina) on growth and carcass composition of hybrid red tilapia (Oreochromis niloticus x Oreochromis mossambicus). Turkish Journal of Fisheries and Aquatic Sciences, 14(2), 471-478.

Al Mamun, M., Hossain, M. A., Saha, J., Khan, S., Akter, T., & Banu, M. R. (2023). Effects of spirulina *Spirulina platensis* meal as a feed additive on growth performance and immunological response of Gangetic mystus Mystus cavasius. Aquaculture Reports, 30, 101553.

Javeed, H., Bhat, F. A., Shah, T. H., Balkhi, M. H., Asimi, O. A., Abubakr, A., ... & Maqsood, H. M. (2021). Effect of dietary *Spirulina platensis* on blood physiology of common carp (Cyprinus carpio var. communis).

Teimouri, M., Amirkolaie, A. K., & Yeganeh, S. (2013). Effect of *Spirulina platensis* meal as a feed supplement on growth performance and pigmentation of rainbow trout (Oncorhynchus mykiss).

Akter, T., Hossain, A., Rabiul Islam, M., Hossain, M. A., Das, M., Rahman, M. M., ... & Abdel-Tawwab, M. (2023). Effects of spirulina (Arthrospira platensis) as a fishmeal replacer in practical diets on growth performance, proximate composition, and amino acids profile of pabda catfish (Ompok pabda). Journal of Applied Aquaculture, 35(1), 69-82.

Sayed, A. E. D. H., & Fawzy, M. A. (2014). Effect of dietary supplementation of *Spirulina platensis* on the growth and haematology of the catfish Clarias gariepinus. J Adv Biol, 5(2).

AlMulhim, N. M., Virk, P., Abdelwarith, A. A., & AlKhulaifi, F. M. (2023). Effect of incorporation of *Spirulina platensis* into fish diets, on growth performance and biochemical composition of Nile Tilapia, Oreochromis niloticus. The Egyptian Journal of Aquatic Research, 49(4), 537-541.

Bakshi, S., Behera, S., Saha, S., Mandal, A., Das, A., Bhakta, D., ... & Patra, P. (2018). Influence of spirulina powder at carotenoids concentration in fin of an ornamental fish Trichogaster lalius. Journal of Entomology and Zoology Studies, 6(1), 870-873.

Abbas, O. T., Mohammed, A. J., & Al-Hussieny, A. A. (2020). The Ability to Use Spirulina sp. as Food for Common Carp Fish (Cyprinus carpio L. 1758). Plant Arch, 20, 532-535.

Kaoud, H. A., Mahran, K. M., Rezk, A., & Khalf, M. A. (2012). Bioremediation the toxic effect of mercury on liver histopathology, some hematological parameters and enzymatic activity in Nile tilapia, Oreochromis niloticus. Researcher, 4(1), 60-70.

Datta, S. N. (2011). Culture of Azolla and its efficacy in diet of Labeo rohita. Aquaculture, 310(3-4), 376-379.