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Fermented soybean meal (FSFM) and *Spirulina* (*Arthrospira platensis*) biomass as potential substitutes for fishmeal for tilapia and other fish species cultivated in intensive systems

Farelo de soja fermentado (FSFM) e biomassa de Spirulina (Arthrospira platensis) como potenciais substitutos à farinha de peixe para tilápias e outras espécies de peixes cultivadas em sistemas intensivos

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ABSTRACT

The constant and significant growth of aquaculture activity necessitates the intensification of cultivation systems and develop more efficient, cost-effective and bioavailable diets. In this context, the use of alternative ingredients to fishmeal, such as fermented soybean meal (FSFM) and *Spirulina* biomass (*Arthrospira platensis*), should be considered. This review article aims to conduct a survey of studies with alternative ingredients to fishmeal for tilapia and other fish species, cultivated in more intensive farming systems, such as the biofloc system.Thus, it can be conclude that these ingredients allow the replacement (partial or total) of fishmeal in diets for Nile tilapia and other fish species. Furthermore, important information about the benefits arising from intensive systems, benefits that justify their use in the cultivation of these animals, were also observed.

KEYWORDS: zootechnical performance; animal nutrition; animal health; biofloc system.

RESUMO

O constante e expressivo crescimento da atividade aquícola, faz necessária a intensificação dos sistemas de cultivo e o desenvolvimento de dietas mais eficientes, baratas e biodisponíveis. Neste sentido, o uso de ingredientes alternativos à farinha de peixe, como o farelo de soja fermentado (FSFM) e a biomassa de Spirulina (*Arthrospira platensis*), devem ser considerados. Esse artigo de revisão tem por objetivo realizar um levantamento de estudos com ingredientes alternativos à farinha de peixe para tilápias e outras espécies de peixes, cultivadas em sistemas de cultivo mais intensivos, como o sistema de bioflocos, e os inúmeros benefícios desses ingredientes e sistemas intensivos para esses animais. Neste sentido, é possível concluir que esses ingredientes permitem a substituição (parcial ou total) da farinha de peixe em dietas para a tilápia-do-Nilo e outras espécies de peixes. Além disso, trazem informações importantes sobre os benefícios advindos de sistemas intensivos, benefícios que fundamentam seu uso no cultivo desses animais.

PALAVRAS-CHAVE: desempenho zootécnico; nutrição animal; saúde animal; sistema de bioflocos.

INTRODUCTION

In intensive fish production systems, feed costs can represent up to 60% of all expenses (BARBOSA et al. 2020). Fishmeal is a crucial ingredient in aquaculture diets because it is a protein with high biological value, and its exclusion from formulations can lead to a decline in zootechnical indices (GLENCROSS et al. 2011, TURCHINI et al. 2019). It is becoming less commercially available, and its cost remains high and constantly fluctuating (WORLD BANK 2020). An increase in animal costs results in higher expenses for aquatic animal production (EL BASUINI et al. 2016 and 2017, HOSSAIN et al. 2016). In this context, the search for alternative ingredients is a strategy for developing diets that reduce costs and optimize production performance (BULBUL et al. 2015, ZHANG et al. 2016, DANIEL 2017, ZHANG et al. 2021). Alternative ingredients are by-products or more accessible products of plant or animal origin, derived from agricultural activities and/or processing industries (ABOWEI & EKUBO 2011).

Soybean meal is one of the most commonly used sources of vegetable protein because of its availability on the market and amino acid profile (SØRENSEN et al. 2009, DANIEL 2018). Complete replacement of fishmeal with this ingredient is not always possible due to its low palatability, high fiber content, and deficiency of some essential amino acids, which tend to limit the use of this meal (EL-DAHHAR & EL-SHAZLY 1993, LIMA et al. 2014). Strategies such as microbial fermentation can improve amino acid profiles and nutrient availability, reduce fibrous components, and improve animal performance and health (HONG et al. 2004, SOTOUDEH et al. 2016, VAN NGUYEN et al. 2018). Fermentation is a bioconversion or metabolic degradation technique carried out by microorganisms (bacteria and/or fungi) that transform complex substrates into simple compounds (BALAKRISHNAN & PANDEY 1996). The preservation technique also improves the nutritional and functional properties of ingredients (ROSS et al. 2002, FRIAS et al. 2008). During the fermentation process, secondary metabolites with prebiotic action (antibiotics, low molecular weight bioactive peptides, enzymes and growth factors) are produced, along with an increase in the population of beneficial microorganisms with probiotic function (MUKHERJEE et al. 2015, DAWOOD & KOSHIO 2019, WANG et al. 2019).

It has been shown that fermented soybean meal (FSFM) can partially replace fishmeal in diets without compromising fish performance (CHOI et al. 2019, WANG et al. 2019, HE et al. 2020a,b). Numerous effects of FSFM on fish health have also been observed, including improvements in biochemical parameters (NOVRIADI et al. 2017 and 2018), lipid metabolism, total antioxidant capacity (JIANG et al. 2018), and intestinal health (WANG et al. 2016, LI et al. 2019, WANG et al. 2019). In addition, increased inflammatory responses and digestive enzyme activity (SHIU et al. 2015, SOTOUDEH et al. 2016, LI et al. 2020) were noted. The use of soybean meal as a substitute for fishmeal has been evaluated in tilapia diets, either partially (AL-KENAWY et al. 2008, LIN & LUO 2011, SHARMA & SAINI 2017) or completely (EL-SAYD & GABER 2002, AJANI et al. 2016).

Another alternative ingredient is the filamentous microalga *Spirulina (Arthrospira platensis)*, which is one of the main phytoplankton organisms studied for aquatic nutrition (AL-ZAYAT 2019, PLAZA et al. 2019, LEITE et al. 2019, SALAH EL-DIN et al. 2021). It is considered a rich source of easily digestible proteins and essential amino acids, as well as minerals, vitamins, fatty acids, and pigments (DE LARA ANDRADE et al. 2005). *Spirulina* is used in animal production as a source of protein and coloring (HABIB et al. 2008). In aquaculture, it has been evaluated as a dietary supplement (MANSOUR et al. 2021, SALAH EL-DIN et al. 2021, SOLIMAN et al. 2021) or as a partial or total substitute for fishmeal (CAO et al. 2018, ERDOGAN 2019, ROOHANI et al. 2019, RAJI et al. 2020), with no adverse effects on the health or performance of tilapia and several other fish species. *Based on this and the importance of Nile tilapia (Oreochromis niloticus*) in national aquaculture, this literature review presents the main findings and improvements resulting from the use of fishmeal substitute ingredients, such as fermented soybean meal and Spirulina microalgae biomass, in the diet of Nile tilapia farmed in different intensive systems.

DEVELOPMENT

National fish farming and fishmeal demand

According to data from the Brazilian Fish Farming Association, in 2023, Brazilian fish production increased by 3.1% compared to the previous year (860,355 tons), totaling 887,029 tons (PEIXE BR 2024). According to the Association, Nile tilapia is the most produced species, accounting for 579,000 tons, representing 65.3% of total fish production. An increase of 5.28% from the previous year (2022) and 103% from 10 years ago (2013). The national ranking of the largest tilapia producers began with Paraná, the largest producer, at 209,500 tons; followed by São Paulo at 75,700 tons; Minas Gerais at 58,200 tons; and finally Santa Catarina at 44,600 tons (PEIXE BR 2024).

By 2050, it is estimated that the world's population will reach 9.7 billion (UN 2021). With this increase in population, the demand for animal protein and more sustainable activities is also increasing. To meet these challenges, intensification of production systems, combined with the relentless search for more sustainable ingredients, is inevitable and necessary. Fish farming is a constantly expanding industry (FAO 2022 and 2024, PEIXE BR 2024), and the demand for sustainability in this sector depends on many factors, including lower feed costs. In intensive fish production systems, feed costs can reach 60% of the total expenses (BARBOSA et al. 2020).

Fishmeal is an important and commonly used ingredient in aquaculture diets. It is a protein of high biological value (above 55% crude protein - NRC 2011), and its exclusion from formulations can lead to a decline in zootechnical indices (GLENCROSS et al. 2011, TURCHINI et al. 2019). In addition to its excellent amino acid profile, it also stands out for its fat-soluble and water-soluble vitamins and high levels of long-chain polyunsaturated fatty acids and minerals (MASUMOTO et al. 1996). As this ingredient becomes less commercially available, its cost, in addition to being high, remains in constant fluctuation (WORLD BANK 2020). This is due not only to increased demand from the feed industry but also to the strong fishing pressure on forage species, leading to the depletion of some of these stocks (NAYLOR et al. 2009). As cost rises, greater expenses will be incurred for the production of aquatic animals (EL BASUINI et al. 2016 and 2017, HOSSAIN et al. 2016). In recent years, there have been constant research efforts to replace fishmeal with alternative ingredients that reduce feed costs and optimize production performance (BULBUL et al. 2015, ZHANG et al. 2016, DANIEL 2018).

Alternative ingredients to fishmeal

Fermented soybean meal (FSFM)

Soybean meal is one of the most commonly used sources of vegetable protein in animal nutrition due to its high protein content, balanced amino acid profile, and availability on the market (SØRENSEN et al. 2009; MUKHERJEE et al. 2016, SHARAWY et al. 2016, WANG et al. 2016, DANIEL 2018, JANNATHULLA et al. 2018). It is a product derived from soybean oil extraction and contains approximately 48% crude protein (MUKHERJEE et al. 2016).

The results recommend partially replacing fishmeal with soybean meal, ranging from 25% to 75%, for tilapia (AL-KENAWY et al. 2008, LIN & LUO 2011, AJANI et al. 2016, SHARMA & SAINI 2017). These findings allow plant protein sources to be incorporated into diets without compromising performance (EL-SAIDY & GABER 2002, AL-KENAWY et al. 2008, LIN & LUO 2011, AJANI et al. 2016, SHARMA & SAINI 2017). Improvements in nutrient use and animal health have also been observed (AJANI et al. 2016), as well as total production and net economic return (AL-KENAWY et al. 2008).

The total replacement of fishmeal is not always feasible (HANSEN et al. 2011, BONALDO et al. 2011, FERRARA et al. 2015). Despite its many qualities, soybean meal contains anti-nutrient factors (ANFs) (LIMA et al. 2014), including protease inhibitors, lectins, phytic acid, saponins, and fiber. In addition, it is less palatable and deficient in some essential amino acids (methionine and lysine) (EL-DAHHAR & EL-SHAZLY 1993, LIMA et al. 2014), limiting the utilization of proteins and other nutrients by animals. Amino acid supplementation can enable complete supplementation (AJANI et al. 2016, EL-SAYD & GABER 2002), but some authors have reported a decrease in consumption (MAHMOUD et al. 2014). These challenges justify the application of the fermentation technique to this ingredient (JAKOBSEN et al. 2015, MONIRUZZAMAN et al. 2018, JANNATHULLA et al. 2019).

Fermentation is a food preservation and processing technique that also enhances the original nutritional and functional properties of foods (FRIAS et al. 2008). The process involves inoculating and providing ideal conditions for the growth of beneficial microorganisms (fungi and/or bacteria) in ingredients of animal or plant origin. The aim is to biologically convert complex substrates into simple compounds, forming typical fermentation products (carbon dioxide and alcohol) (BALAKRISHNAN & PANDEY 1996). The final product will also be rich in populations of probiotic microorganisms and secondary metabolites such as antibiotics, low-molecular-weight bioactive peptides, enzymes, and growth factors, all of which have prebiotic action (BALAKRISHNAN & PANDEY 1996, KADER et al. 2011, MUKHERJEE et al. 2015, DAWOOD & KOSHIO 2019, WANG et al. 2019).

For animal nutrition, the main fermentation technique used is solid-state fermentation (SSF) (YANG et al. 2021). This technique involves inoculating microorganisms into grains or bran using moisture levels between 40% and 80% (ORIOL et al. 1988a,b, BORZANI et al. 1999, YANG et al. 2021) to produce fermented dry ingredients in the form of whole grains or powder (SUBRAMANIYAM & VIMALA 2012). *Aspergillus* spp., *Rhizopus* spp. and *Lactobacillus* spp. are the main microorganisms used in this method (SUBRAMANIYAM & VIMALA 2012) for the production of enzymes, organic acids, and biopesticide (LU et al. 1998, BATTAN et al 2006). It can also be used to develop animal feed ingredients (MUKHERJEE et al. 2015, DAWOOD & KOSHIO 2019, WANG et al. 2019).

The main microorganisms used in the fermentation technique are from the *Bacillus* genus (WONGPUTTISIN et al. 2007, TENG et al. 2012), *Aspergillus* (ILYAS et al. 1995, HIRABAYASHI et al. 1998, HONG et al. 2004, KISHIDA et al. 2000, FENG et al. 2007a,b), *Lactobacillus* (AMADOU et al. 2010a,b, CHI & CHO 2016, WANG et al. 2016), and *Saccharomyces* (CHI & CHO 2016, HASSAAN et al. 2018). Each one is responsible for producing different products (lactic acid, ethanol, acetic acid, among others) because they respond differently to each substrate (NIBA et al. 2009). For example, Lactobacillus tends to produce lactic and citric acid, while yeasts produce ethanol and CO_2 (SUBRAMANIYAM & VIMALA 2012).

Studies have shown that fermentation increases the bioavailability and digestibility of nutrients while reducing anti-nutrient content in plant proteins (WANG et al. 2016, HASSAAN et al. 2018). In this fermentation process, the microorganisms involved in bioconversion degrade protein macromolecules into soluble low-molecular-weight compounds. These compounds, made up of small chains of amino acids and bioactive peptides, are better assimilated, improving the digestion and absorption of nutrients, as well as animal health (AZARM & LEE 2012, SANJUKTA & RAI 2016). In addition, other advantages and benefits of fermented soybean meal (FSFM) have been observed, including the following:

- Improved nutritional quality and antioxidant activity in soybean meal (DA SILVA et al. 2018);
- Source of enzymes, organic acids, and growth factors (KADER et al. 2011, MUKHERJEE et al. 2015, DAWOOD & KOSHIO 2019, HA et al. 2019, WANG et al. 2019);
- Increase in fibrinolytic enzyme activity, in vitro trypsin digestibility, and nitrogen solubility (MUKHERJEE et al. 2016, SHARAWY et al. 2016, WANG et al. 2016, JANNATHULLA et al. 2018);
- The crude protein content was increased by approximately 10% compared with the original ingredient without altering the essential amino acid profile (HONG et al. 2004);
- Decreases fiber content, ANF levels, and levels of toxic ingredients, facilitating absorption, use, and palatability of nutrients. Thus, improvements in feed efficiency and animal performance can be achieved (MAKKAR 1993, YAMAMOTO et al. 2010, JAKOBSEN et al. 2015);
- Immunostimulant action and tolerance to environmental stressors improve the health of farmed animals (MONIRUZZAMAN et al. 2018, JANNATHULLA et al. 2019).

FSFM is rich in bioactive peptides and can have a high protein and amino acid content and lower ANF and allergen content than soybean meal (SHIU et al. 2015, WANG et al. 2016, CHI & CHO 2016, LI et al. 2019). It is also rich in bioactive compounds with regulatory and functional roles, acting as an antihypertensive, antimicrobial, antioxidant, and antidiabetic agent (SINGH et al. 2014, SANJUKTA & RAI 2016).

FSFM has been widely tested as a fishmeal substitute and functional food in aquaculture diets. FSFM can replace 25%–60% of fishmeal in fish diets without compromising performance and, in addition, has numerous benefits for animal health, as shown in Table 1. Beneficial effects on fish health with the inclusion of FSFM in diets have also been reported: improved non-specific immune responses, reduced inflammation, modulation of the microbiota, and increased activity of digestive enzymes (YAMAMOTO et al. 2010, SHIU et al. 2015, LEE et al. 2016, ILHAM & FOTEDAR 2016, SOTOUDEH et al. 2016, NOVRIADI et al. 2017 and 2018, CHOI et al. 2019, RAHIMNEJAD et al. 2019). In addition, changes in biochemical and hematological parameters, lipid metabolism, hepatointestinal health, and total antioxidant capacity have also been observed (YAMAMOTO et al. 2010, AZARM & LEE 2012, BARNES et al. 2015, WANG et al. 2016, JIANG et al. 2018, NOVRIADI et al. 2018, WANG et al. 2019).

Table 1. Studies using fermented soybean meal (FSFM) from various fish species.

Tested parameters	Species/Weight (g)	Levels tested	Main results/Conclusion	Reference
Performance	Hybrid tilapia *(Oreochromis niloticus × O.* aureus)/0.36	Control: No FP; Diet I: 0-20% FP or 57-31.6% DSBM; Diet II: 0-20% FP or 51-28.3% FSFM with encapsulated methionine	Lower performance on diets without PF. The addition of encapsulated methionine did not improve the growth of the group without FP.	WU et al., 2003
Performance, feed efficiency, digestibility, hematology, *biliary* status, and hepatointestinal morphology	Rainbow trout (*Oncorhynchus* mykiss*)* /)/12.0	FP Diet; FS Diet; FSFM I diet: initial addition of 30% water (fermented for 7 h); FSFM II diet: 5% (10 h).	Better performance and feed efficiency in groups fed the FP and FSFM II diets; Better biliary and hepatointestinal health on fermented diets	YAMAMOTO et al. (2010)
Performance, biochemical parameters, and digestibility	Black snapper *(Acanthopagrus* schlegeli)/1,17	FSFM (0, 80, 160, 240 and 320 g/kg) supplemented with methionine, lysine, and taurine to replace FP	Replacing FP with FSFM supplemented by up to 40% without compromising performance	AZARM & LEE, 2012
Performance, digestive enzyme activity, and changes in the	Grouper *orange-spotted (Epinephelus coioides)/4.46*	Control with FP, replacement of FM by FS at 10%, 20 and 30% and at 10, 20, 30 and	Replacing FP with FSFM with up to 30% without compromising performance and feed efficiency. Hepatic,	SHIU et al. 2015

liver and distal intestine		40% by FSFM	intestinal, and digestive improvement after replacing FP with FS and FSFM	
Performance, organosomatic index, and intestinal histology	Trout strains *Shasta x McConaughy (Oncorhynchus mykiss)/23.4*	Diets with 0, 35 or 50% FSFM and 40, 15 or 0% FP	Diets containing up to 35% FSFM and 15% FP are acceptable for both strains without compromising performance and intestinal histology.	BARNES et al. 2015
Performance, enzyme activity, and blood physiology	Barramundi (*Lates calcarifer)* / *5.04*	FS or FSFM supplemented or not with organic selenium replacing FP	Performance improved with the use of organic selenium for FS and FSFM, but did not differ between the FP diet groups.	ILHAM & FOTEDAR, 2016
Performance, body composition, and digestive enzyme activity	Caspian brown trout (Salmo *trout* caspius)/2.1	FP replaced by FS or FSFM untreated or irradiated with -radiation at 15 and 30 kGy	The gamma radiation level used was not efficient, but FS fermentation improved the final weight, proteolytic enzyme activity, and body composition.	SOTOUDEH et al. 2016
Dry matter and protein digestibility of FSFM diets compared with FS and FM	Grouper orange-*spotted (Epimetheus coioides)/22.01*	Control with FP; Test diets with 300 g/kg FS or FSFM replacing FP.	Improved apparent digestibility of FSFM diets	ZHUO et al. (2016)
Performance, immune response, and intestinal morphology	Psetta maxima - turbot*(Scophthalmus maximus)/5.11*	Control with PF; Test diets with PF replacement by FS or FSFM Lactobacillus plantarum at 15, 30, 45 and 60%	Replacement of FP protein by FSFM with L. plantarum by up to 45% without affecting the variables studied.	WANG et al. 2016
Performance, body composition, and enzymatic anti-oxidant activity	Rockfish (*Sebastes schlegeli*)/1.2	FSFM (0, 8, 16, 24, 32%) replacing the FP protein with 0, 10, 20, 30 and 40%, approximately	Replacing FP protein with FSFM with up to 40% had no negative effect on animal performance.	LEE et al. 2016
Intestinal microbiota	Atlantic salmon*(Salmo salar)/50*	Control with 30% FP, FS with 30% or FSFM with 30%	The use of FSFM promoted intestinal health and protection in salmon.	CATALÁN et al., 2017
Performance, fatty acid profile, and body composition	Japanese sea bass*(Lateolabrax japonicus*)/13.3	FSFM (0, 25, 50 and 75%) replacing FP	Replacing FP with FSFM with up to 25% without compromising performance, meat quality, or feed use	LIANG et al., 2017
Performance and economic viability	*Anabas testudineus/1*,03	Control; FSFML replacing FP with 0, 25, 50, 75, or 100% of FP's PB	A performance similar to that of the control was observed up to an FSFML level of 50%. Economically, FSFML can be included in up to 50% of PF protein.	KADER et al. 2018
Performance, morphological condition, and serum biochemistry of the liver and distal intestine	Pompano*(Trachinotus carolinus)/17.01*	FSFM (0, 25, 50, 75 and 100%) replaces the FS	Improvement in biochemical parameters according to the inclusion of FSFM. Improved intestinal health with the two highest contents of fermented foods	NOVRIADI et al. 2018
Performance,	Largemouth Bass *(Micropterus*	FSFMR (0, 20, 40 60 g/kg protein) replaced by	The best performance was	JIANG et al. 2018

body composition, and plasma biochemical parameters	*salmoides)/17.1*	FS	observed when substituting 40g/kg. Improved lipid metabolism and antioxidant capacity	
Performance, morphology, and intestinal microbiota	Yellow croaker*(Larimicthys* crocea)/10.0	FSFM (0, 15, 30, 45, 60 and 75%) replacing FP	FSFM replacement of up to 45% of FP without negative effects on performance and intestinal integrity.	WANG et al. (2019)
Performance and feed use	Rainbow trout (*Oncorhynchus* mykiss)	Control with FM; FSFM 1 and FSFM 2 (fermentation techniques), both with 20, 40 and 60% replacing FP.	Improvement in oxidative stress with the use of FSFM. Replacement of FP by up to 40% with fermented products with no effect on growth or feed use	CHOI et al. (2019)
Performance, ANF levels, digestibility, and intestinal health	Psetta maxima - turbot*(Scophthalmus maximus)/8,53*	Control with FP (0%), 30%, 45% and 60% with FS and 30%, 45% and 60% with FSFM	Reduced ANF levels with fermentation, improved performance and digestibility of up to 45% of FSFM; improved intestinal health at the two highest levels	LI et al. (2019)
Performance, antioxidant status, intestinal morphology, and inflammatory response	Psetta maxima - turbot*(Scophthalmus maximus)/7,57*	Control with FP; 45% FS or FSFM with Enterococcus faecium)	Fermentation neutralized the negative effects of FS, improved antioxidant capacity, suppressed inflammatory responses, and modulated intestinal microbiota	LI et al. (2020)
Performance, body composition, and biochemical and intestinal histology	Largemouth Bass*(Micropterus salmoides)/4.43*	Control of 35 g/kg FP; Replacement of FP by FS and FSFM at 15%, 30%, 45%, and 60%	Replacing FSFM with up to 30% PF without compromising performance, digestibility, and intestinal health	HE et al. (2020a)
Performance, histology, and intestinal microbiota	Largemouth Bass *(Micropteus salmoides)/4.43*	Control 35g/kg FP; Replacement of FP with FS or FSFM at 30% and 60%	Supplementation with FSFM of up to 30% of FP in diets without adverse effects on performance and intestinal health	HE et al. (2020b)
Performance, intestinal histology, enzyme activity, and expression of proinflammatory genes	Gentian grouper*(Epinephelus fuscoguttatus* × E. lanceolatus)/9.0	FP control; Replacing FP with FSFM by 20% or 40%	Replacement with FSFM at 20-40% of FP affected performance, intestinal morphology, and expression of genes related to the immune system.	ZHANG et al. (2021)
Performance, carcass, and liver	Asian sea bass*(Lates calcarifer*)/1.27	Control-unattractive FP; Control + FP with attractions; Replacement of FP mixtures of 20, 40, 60, 80, and 100% protein with 60% PBM and 40% FSFM	FSFM replacement for up to 60% of the PF without compromising performance	HONG et al. (2021)
Performance, microbiology, enzyme activity, and intestinal histology	South African catfish - jundiá*(Rhamdia* quelen)/	Control with FP; Replacing FP with FSFM Lactobacillus acidophilus at 7, 14, 21 and 28%	FSFM replacement by up to 21% without loss of performance. Lowest count of *Vibrionaceae at 7-21%*. FSFM did not affect the counts of heterotrophic bacteria, enzymatic activity, or intestinal histology.	DE OLIVEIRA et al. (2022)

Performance and intestinal health	*Nile tilapia (Oreochromis niloticus)*	Plant-based diets including different levels (7%, 14%, 21% and 28%) of FSFM	The addition of 7% FSBM makes it possible to completely replace fishmeal without compromising fishmeal performance. Levels >21% of FSFM improved the intestinal health of tilapia.	PICOLI et al. 2022

FP: Fish meal; FS: Soybean Meal; FSFM: Fermented soybean meal; DSBM: Hulled soy flour; PBM: Poultry by-product; Aa's: amino acids; kGy: kilo Gray; kDa: kilo Dalton; FSFMR: Fermented soybean meal residue; FSFML: Fermented with a mixture of soy flour and squid by-product; ANF's: Anti-nutritional factors.

Biomass of spirulina (Arthrospira platensis)

Unicellular proteins, including microalgae, yeasts, and bacteria, are promising alternative sources for replacing fishmeal in fish diets (HARDY 2010). They are often used as ingredients in aquatic organisms at different stages of development (ERDOGAN 2019, RAJI et al. 2020, MANSOUR et al. 2021). Among them, *spirulina* is one of the potential candidates for this substitution. It is a filamentous microalga with a smooth surface that contains phycocyanin and chlorophyll as its main photosynthetic pigments, which are responsible for its blue-green color (CAPELLI & CYSEWSKI 2010, ALI & SALEH 2012) (Figure 1).

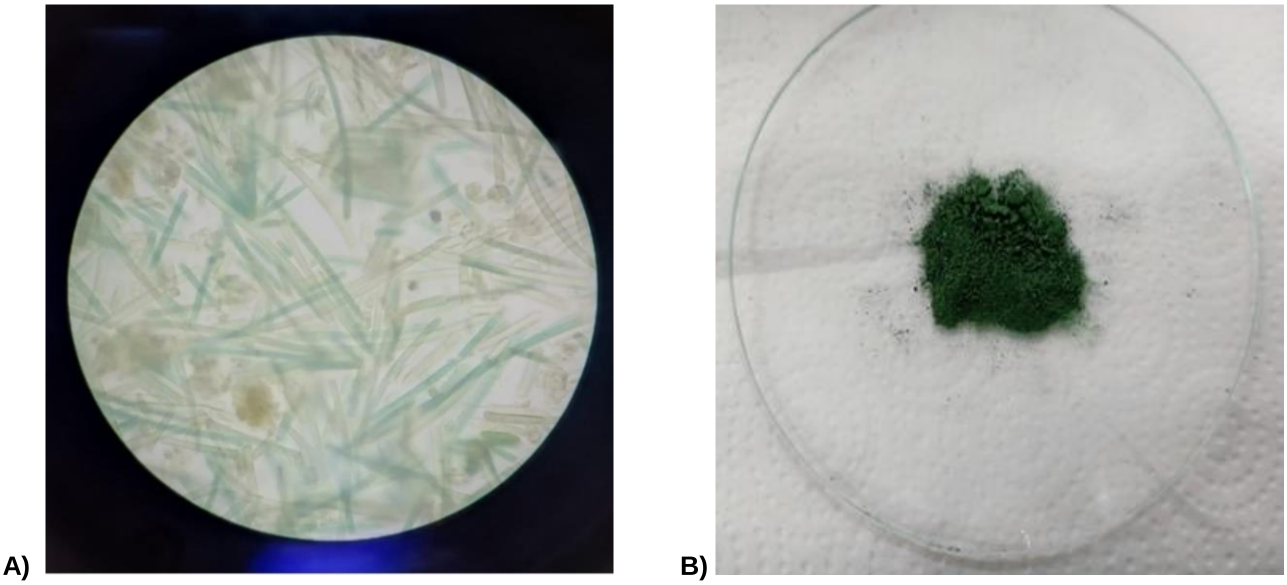

Figure 1. Biomass of *spirulina (A. platensis)* under (A) 40x optical microscopy (A) and in the wild (B).

Spirulina contains significant amounts of omega-6 polyunsaturated fatty acids, particularly gamma-linolenic acid and linoleic acid (HENRIKSON 1995, COLLA et al. 2004, BABADZHANOV et al. 2004). In addition, its composition includes high levels of iron, calcium, phosphorus, vitamins (vitamin E and B12), and pigments (phycocyanin, carotenoids and chlorophyll-a) (CAPELLI & CYSEWSKI 2010, ALI & SALEH 2012). Because of the absence of cellulose in the cell wall and the lack of phytate and oxalates, *spirulina* facilitates the assimilation of nutrients at the intestinal level (GUTIÉRREZ-SALMEÁN et al. 2015). It is a rich source of digestible protein (up to 70% of its protein content) and has a well-balanced amino acid profile (AL-DHABI & ARASU 2016, TOKU & ÜNAL 2003). *Spirulina* also plays a role in the treatment of various human pathological conditions, such as hepatotoxicity, cardiovascular diseases, cancer, and hyperlipidemia (HABIB et al. 2008, NAGAOKA et al. 2005). It also allows for greater inclusion in the substitution of various components in animal feed formulations (AHMADZADENIA et al. 2011, SIRAKOV et al. 2012).

In recent years, research has reported improvements in performance with the use of *spirulina* as a supplement or substitute for fishmeal in tilapia diets (Tables 2 and 3) (PLAZA et al. 2019, AL-ZAYAT 2019, ELABD et al. 2020, MANSOUR et al. 2021) and other fish species, such as the African catfish (*Clarias gariepinus*) (RAJI et al. *2018 and 2020), common carp (Cyprinus carp*) (ABDULRAHMAN & AMEEN 2014), and brown trout (Salmo truta caspius) (ROOHANI et al. 2019). In addition, benefits related to fish health, such as improved biochemical parameters (ABDEL-DAIM et al. 2020, MANSOUR et al. 2021, SOLIMAN et al. 2021), histological parameters (ABU-ELALA et al. 2016), and antioxidant capacity (AWED et al. 2020, ELABD et al. 2020, SALAH EL-DIN et al. 2021), are also noteworthy.

According to Tables 2 and 3, *spirulina* can be included in Tilapia diets as a supplement of up to 20%. As a substitute for fishmeal, up to 75% of the same species and for African catfish*(Clarias gariepinus*) (RAJI et al. 2018, ROSENAU et al. *2021), common carp (Cyprinus carp*) (ABDULRAHMAN & AMEEN 2014), and brown trout (Salmo truta caspius) (ROOHANI et al. 2019). *Complete replacement of fishmeal with spirulina biomass* (100%) has also been reported for Prussian carp (Carassius auratus gibelio var. CAS III) (CAO et al. 2018) and African catfish (RAJI et al. 2020), without harming the health or performance of these animals.

Table 2. *Studies using spirulina (Arthrospira platensis) as a supplement for Nile tilapia (Oreochromis* niloticus).

Tested parameters	Weight (g)	Levels tested as supplements	Main results/Conclusion	Reference
Performance, feed use, proximate body composition, and hemato-biochemical parameters	0.83	Control: Plant-based diet without SP; plant-based diets including 0.125, 0.25, 0.5, 0.75 and 1% SP	Supplementation of a plant-based diet with 0.5-0.65% SP improved performance, feed use, and blood biochemical parameters	MANSOUR et al. (2021)
Performance, feed use, and carcass composition	6.0	Control: DB without SP; diets containing 2.5, 0.5, 5 and 7.5% SP	Supplementation with 7.5% SP improved performance, protein use, and blood	AL-ZAYAT, 2019
Performance, hematological parameters, intestinal microbiota, and fillet quality	109.0	Control: DB without SP; Diet with 3% SP	Supplementation with 3% SP improved performance and fillet color without changing the intestinal microbiota. Increases in cortisol and triglyceride levels	PLAZA et al. (2019)
Performance and fillet composition	1.0	Control: DB without SP; Diet with 20% SP supplementation	Supplementation with 20% SP increased the protein level of the filets and kept performance (except S and CAA) of the control.	LEITE et al. (2019)
Reproductive parameters	55.0	Control: DB without SP; Diets including 5, 7.5, 10 and 20% SP	SP supplementation of 0.5-2% improved reproductive parameters	WAHB & SANGAK, 2017
Antioxidant capacity, DNA fragmentation, and protein fraction (gel electrophoresis - SDS-PAGE)	9.5	Control (T1): No exposure to EtBr and no SP; T2: EtBr 10 μg L^{-1}; T3: EtBr 10 μg L^{-1} EtBr + 200 mg L^{-1} SP; T4: EtBr 100 μg L^{-1}; T5: EtBr 100 μg L - 1 EtBr + 200 mg L^{-1} SP	Supplementation with 200 mg L^{-1} of SP protected against the negative effects on DNA and antioxidant capacity of tilapia exposed to ethidium bromide	SALAH EL-DIN et al. 2021
Biochemical, histopathological (brain, liver and kidneys), oxidative stress, and hematological indices	9.5	Control (T1): DB without exposure; T2: DB 15 mg/L $CuSO_4$; T3: DN + 0.25% SP 15 mg/L $CuSO_4$; T4: DB 15 mg/L CuO-NPS; T5: DB + 0.25% SP 15 mg/L CuO-NPS	Supplementation with 0.25% SP in fish exposed to $CuSO_4$ and CuO-NPs protected against histopathological, biochemical, and hematological alterations and oxidative stress	SOLIMAN et al. (2021)
Biochemical, histopathological (brain, liver and kidneys), oxidative stress, and hematological indices	9.5	Control (T1): DB without exposure; T2: DB 15 mg/L $CuSO_4$; T3: DN + 0.25% SP 15 mg/L $CuSO_4$; T4: DB 15 mg/L CuO-NPS; T5: DB + 0.25% SP 15 mg/L CuO-NPS	Supplementation with 0.25% SP in fish exposed to $CuSO_4$ and CuO-NPs protected against histopathological, biochemical, and hematological alterations and oxidative stress	SOLIMAN et al. (2021)
Performance and tissue antioxidant capacity	40.0	Control: DB; SS: 5.8 mg/L intoxicated SS; SP: Diet with 1% SP; SP/SS: 1% spirulina diet and intoxicated with 5.8 mg/L intoxicated SS	Supplementation with 1% SP did not alter the performance, but suppressed tissue oxidative stress induced by exposure to SS.	AWED et al. (2020)
Performance, digestive and biochemical enzymes, immune	26.0	Control: DB without SP; diets containing 0.25% or 0.5% SP	Supplementation with 0.25-0.5% SP nanoparticles improved performance,	ELABD et al. (2020)

status, antioxidants, resistance to *Aeromonas* veronii, and physical stressors			immune response, antioxidants, digestive enzymes, gene expression, and controlled infection	
Enzymatic and biochemical antioxidant biomarkers of lipid peroxidation	60.0	Control: no SP; 1% SP diet and no CPF exposure (15 g/L); diet with CPF exposure without SP; diet with CPF exposure 0.5%-1% SP	Supplementation with 1% SP improved enzymatic and biochemical antioxidant biomarkers and lipid peroxidation	ABDEL-DAIM et al., 2020
Performance and visceral indices, fillet composition, and texture	26.8	Control: *DB; Diets 0.25% and 0.5% SP; Diets 0.25% and 0.5% S. cerevisiae; Diets 0.25% and 0.5% Rubrivivax gelatinosus*	Supplementation with 0.25-0.5% SP did not affect performance, increase nutritional quality, or preserve the texture characteristics of the filets.	GRASSI et al. (2020)
Final weight, histopathology, chromosomal abnormalities, DNA damage and biochemical-hematological parameters	100.0	Control: no SP and no exposure to CF; CF: DB + exposure to FC; FC+SP: DB + 0.5% SP + exposure to CF; SP: DB + 0.5% SP	Supplementation with 0.5% SP reduced the appearance of chromosomal abnormalities and DNA damage and improved erythrogram	MAHMOUD et al. (2019)
Markers of liver and kidney damage, serum biochemistry, and antioxidant status	60.0	Control: DB; SP1%: DB + 1% SP; DZN: DB + diazinon (0.28 mg/L); DZN-SP0.5: DB + DZN + 0.5% SP; DZN-SP1: DB + DZN + 1% SP.	Supplementation with 1% SP improved liver and kidney damage markers, serum biochemistry, and antioxidant status	ABDELKHALEK et al., 2017
Performance, body composition, and biochemical parameters	7.0	Control: *DB without SP; Diet with 1% A. fusiforms*; Diet with 1% A. platensis	Supplementation with 1% SP*(A. fusiforms and A. platensis)* improved performance, body composition, and biochemical parameters	BELAL et al. (2012)

SP: Spirulina; FM: Fish meal; DB: Basal diet; S: Survival; AAC: Apparent feed conversion; CuSO4: copper sulfate; CuO-NPs: copper oxide; EtBr: ethidium bromide; FC: chemical products; CPF: chlorpyrifos; SS: sodium sulfate.

Table 1 Studies using spirulina*(Arthrospira platensis*) as a fishmeal substitute for tilapia and other fish species.

Tested parameters	Species/Weight (g)	Levels tested as a substitute	Main results/Conclusion	Reference
Productive performance, intestinal histomorphometry, plasma biochemistry and oxidative stress	Nile tilapia *(Oreochromis niloticus/0.23)*	Control (0%): DB without SP 0% and 33% 66% 100% replacement of FM by SP	SP completely replaced FM without adverse effects on intestinal morphometry, protein metabolism and antioxidant response. Replacing 66% of FM with SP improved the production performance, regardless of the rearing system (clean water × BFT)	PICOLI et al. (2024)
Performance, carcass composition, and hematology	*Red hybrid tilapia (Oreochromis niloticus x O.* mossambicus) /0.206	Control: DB with FM; Diets replacing PF with *spirulina* at 50, 75, 100%	The replacement of 75% of FM with *spirulina* did not differ from the FM control in terms of animal performance and carcass composition. Cost-effectiveness of spirulina-based diets compared with FM	EL-SHEEKH et al. (2014)
Organosomatic indices, feed use, carcass composition, and blood biochemical parameters	Nile tilapia *(Oreochromis niloticus)/0.89*	Control: *DB without spirulina*; diets including 30, 45, 60 and 75% (0% FM) spirulina	Replacing 30% of FM with *spirulina* improved performance and organosomatic indexes, feed utilization, and carcass composition and reduced triglycerides compared with the control.	VELASQUEZ et al. (2015)

Performance, body and mineral composition, and hepatointestinal histology	Nile tilapia *(Oreochromis niloticus)/0.02*	Control: Vegetable diet with corn gluten as a protein source; Seaweed diets 0, 25, 50, 75, and 100% gluten replacement; Diet with 100% *spirulina* to replace gluten	Replacing 100% corn gluten in vegetable diets with *spirulina improves performance*	HUSSEIN et al. 2013
Performance and obvious nutrient digestibility	African catfish - *catfish(Clarias gariepinus*)/58.05	Control: DB with FM; Diet with 100% replacement of FM with SP; Diet with 100% replacement of PF with *Chlorella* vulgaris	Replacing 100% of the FM with SP improved the performance. Higher clear macronutrient digestibility coefficient	RAJI et al. (2020)
Performance, body composition, and sensory analysis	Common carp*(Cyprinus* carp)/32.7	Control: DB with FM; Diets with FM replacement by SP at 5, 10, 15 and 20%	Replacing 5-20% of FM with vitamin C SP+ improved weight gain and survival. Treatment with 10% *spirulina* resulted in the best sensory quality	ABDULRAHMAN E AMEEN, 2014
Performance, organosomatic index, body composition, and skin pigmentation	Malawi dolphin*(Cyrtoc ara* moorii)/3.15	Control: DB with FM; Diets with FM replacement by SP at 5, 10, 15 and 20%	Replacing 5%–15% of FM with SP improved performance and feed efficiency. The skin of animals fed 15% SP instead of FM showed greater pigmentation (carotenoids)	ERDOGAN 2019
Performance, hemato-biochemical, and antioxidant response	African catfish - *catfish (Clarias gariepinus*)/42.07	Control: DB with FM; Diet with 50% and 75% replacement of FM; diet with 50% and 75% replacement of PF with *Chlorella vulgaris*	Replacing 75% of FM with SP improved performance and hemato-biochemical and antioxidant response	RAJI et al. 2018
Performance, meat quality, and fatty acid content	African catfish - *catfish(Clarias gariepinus*)/50.0	Control: DB with FM; diet with 100% replacement of FM with SP.	Replacing 100% of FM with SP: harmed GDP, but FAC was not affected; altered visual characteristics and meat/skin quality; higher values/proportion of omega-3 and 6 FA	ROSENAU et al., 2021
Performance, body composition, fatty acid and amino acid profile, and pigmentation	Caspian brown trout (S *almo trout* caspius)/11.0	Control: DB with FM; diets replacing FM with SP at 2, 4, 6 and 8%	Replacing 8% of FM with SP improved performance, carcass composition, and pigmentation.	ROOHANI et al. (2019)
Performance, feed use, and digestive parameters	Prussian carp*(Carassis* auratus gibelio var. *CAS III*) 5.0	Control: DB with FM; Diets replacing FM with SP at 50, 75 and 100%. Diets with 100% + 2% dicalcium phosphate and 100% + 0.28% crystalline lysine	The partial or total replacement (50, 75 or 100%) of FM with SP did not affect the performance. Total replacement improved diet digestibility and antioxidant capacity compared with the control.	CAO et al. 2018
Metabolic and growth responses	Zebrafish *(Danio* rerio)/0.113	Six diets with SP inclusion levels of 0%, 2%, 4%, 6%, 8%, and 10% (SP0-SP10)	Supplementation with SP (6%) has substantial potential as a growth promoter, positively influencing lipid metabolism and antioxidant enzyme activity without compromising survival.	COLI et al. (2024)
Composition and apparent digestibility coefficients, *essential macronutrients, energy, amino*	Atlantic salmon*(Salmo salar* L.)/24.7	SP meal: 60% crude protein, 20 MJ kg^{-1} crude energy, 16% nitrogen-free extract (NFE), 10% ash, 5% moisture, and 4% crude lipid.	SP meal as an alternative source of protein, rich in nutrients and low in anti-nutritional compounds and contaminants; diet containing 20% SP showed high digestibility of essential amino acids and long-chain n-3 polyunsaturated fatty acids	SEAN et al. (2023)

acids and fatty acids for spirulina flour.				
Growth, nutritional value, and health status	*Micropterus* salmoides/130	Control (SP0): 50% FM and no SP or PSP. The experimental diets contained 0.3% PSP, 3.0% SP (SP3 replacing 4.4% FM), and 6.0% SP (SP6 replacing 9.6% FM).	Replacing fishmeal with 3%–6% SP and adding 0.3% PSP can improve growth performance, protein efficiency, muscle nutritional value, liver health, antioxidant capacity, intestinal digestive enzyme activity, and intestinal microbiota.	ZHANG et al. (2024)

SP: *Spirulina*; FM: Fish meal; DB: Basal diet; PSP: Purified polysaccharides from *S. platensis*; PIB: Weight gain; AAC: clear feed conversion.

Biofloc system (BFT)

Biofloc cultivation or biofloc technology (BFT) is an intensive system with low water exchange achieved through the formation of a rich microbial community that cycles nutrients (EMERENCIANO et al. 2013). This system has great potential for aquaculture, as it makes it possible to increase aquaculture activity with less risk of disease and minimal environmental impact (MARISCAL-LAGARDA et al. 2012, BUHMANN et al. 2015, HU et al. 2015).

In the BFT system, the growth of specific microbial communities is stimulated through intense aeration and maintaining the correct carbon-nitrogen (C:N) ratio in the environment (AVNIMELECH 2007, EMERENCIANO et al. 2012). Various microorganisms are present in these flocs, predominantly bacteria (autotrophic and heterotrophic), but also yeasts, microalgae, ciliates, rotifers, and nematodes (MONROY-DOSTA et al. 2013). These microorganisms play crucial roles in water quality, recycling organic matter, and serving as food for cultivated aquatic organisms, while directly competing with other pathogenic microorganisms in the environment (AZIM & LITTLE 2008, EMERENCIANO et al. 2013 e 2017).

The main beneficial bacteria found in the BFT system are Sphingomonas paucimobilis, Pseudomonas luteola, Pseudomonas mendocina, Micrococcus, Bacillus sp., Nitrospira sp., and Nitrobacter sp. (MONROY-DOSTA et al. 2013). These dominant genera are associated with effective biocontrol of pathogenic microorganisms in the environment (HARGREAVES 2006, AVNIMELECH 1999 and 2009, CRAB et al. 2012). In addition, they produce rich microbial biomass (THOMPSON et al. 2002, MONROY-DOSTA et al. 2013), which can be used as food for cultivated species (MONROY-DOSTA et al. 2013, MARTÍNEZ-CÓRDOVA et al. 2015). Pathogenic bacteria of the *Aeromonas* and *Vibrio* genera tend to be found in the first few weeks of BFT cultivation and then stop multiplying (MONROY-DOSTA et al. 2013). This occurs because of competitive exclusion as the proliferation of beneficial bacteria increases (WU et al. 2012, MONROY-DOSTA et al. 2013).

Studies that allow the use of sub-optimal levels of protein for fish are essential for making the activity viable and assessing the potential of animals and systems (FURUYA et al. 2005, COSTA et al. 2009, AZIM & LITTLE 2008, DA SILVA et al. 2018, HISANO et al. 2019). The microbial biomass produced in this system can be used as a natural food source, providing up to 50% of the protein needs of tilapia (AVNIMELECH 2007). Consequently, it is possible to reduce crude protein in the diets of these animals by more than 30% without compromising performance (AZIM & LITTLE 2008). In addition, lower feed conversion rates compared to cultivation in clean water were also achieved (LUO et al. 2014).

Growing tilapia in BFT

Tilapia are well adapted to this system, mainly because they are filter feeders, robust and fast-growing (AVNIMELECH 2011 and 2015). They can feed on the flakes present in the culture medium, regardless of the size of the aggregate (EKASARI 2014). These flakes are rich in protein, ranging from 24% to 32% (AZIM & LITTLE 2008, ELÍAS et al. 2015, LIMA et al. 2018). BFT technology also allows tilapia to be farmed at high densities and high yields (10 to 40 kg/m³), even compared to clear water farming (EKASARI 2014).

An increase in density from 15 to 45 tilapia/m³ during the fattening phase of BFT resulted in higher productivity (LIMA et al. 2015), similar to that observed by WIDANARNI et al. (2012). It is believed that BFT farming can also improve the health of tilapia because the flakes contain various bioactive compounds, including essential fatty acids, carotenoids, free amino acids, and chlorophylls (JU et al. 2008), minerals (TACON et al. 2002), and vitamin C (CRAB et al. 2012). All of these compounds have positive effects on aquatic organisms, such as increasing their antioxidant status, growth, reproduction, and immune response in animals (TACON et al. 2002, JU et al. 2008, CRAB et al. 2012).

Animals raised in this system can also benefit from the reduced presence of exogenous pathogens because it is a closed system. Some studies have shown that potentially pathogenic bacteria, such as *V. harveyi*, can be reduced in BFT under suitable cultivation conditions (CRAB et al. 2010 and 2012, ZHAO et al. 2012).

CONCLUSION

The search for greater efficiency and sustainability in aquaculture has made it essential to search for alternative ingredients to fishmeal, as well as more intensive and biosecure farming systems. *In this context, this literature review highlights the significant potential of ingredients such as fermented soybean meal (FSBM) and spirulina biomass* (Arthrospira platensis) in aquaculture diets.

It can be concluded that these ingredients can be partially or completely substituted for fishmeal in diets for Nile tilapia and other fish species, offering numerous benefits in terms of performance and health parameters. In addition, valuable information on intensive systems, such as the biofloc system, was highlighted. These benefits provide a solid basis for its use in the cultivation of these animals.

REFERENCES

ABDEL-DAIM M et al. 2020. *Spirulina platensis* Reduced Oxidative Damage Induced by Chlorpyrifos Toxicity in Nile Tilapia (*Oreochromis niloticus*). Animals 10: 12p.

ABDELKHALEK N et al. 2017. Protective role of dietary *Spirulina platensis* against diazinon-induced Oxidative damage in Nile tilapia; *Oreochromis niloticus*. Environmental Toxicology and Pharmacology 54: 99-104.

ABDULRAHMAN NM & AMEEN HJH. 2014. Replacement of fishmeal with microalgae *Spirulina* on common carp weight gain, meat and sensitive composition and survival. Pakistan Journal of Nutrition13: 93–98.

ABOWEI JFN & EKUBO AT. 2011. A review of conventional and unconventional feeds in fish nutrition. British Journal of Pharmacology and Toxicology 2: 179–191.

ABU-ELALA NM et al. 2016. Effects of Dietary Supplementation of *Spirulina platensis* and Garlic on the Growth Performance and Expression Levels of Immune-related Genes in Nile tilapia (*Oreochromis niloticus*). Journal of Aquaculture Research and Development 7:10p.

AHMADZADENIA Y et al. 2011. Effect of replaciru fishmeal with *Spirulina* on carcass composition of rainbow trout. Journal of Agricultura and Biological Science 6: 66-71.

AJANI EK et al. 2016. Total replacement of fishmeal by soybean meal with or without methionine fortification in the diets of Nile tilapia, *Oreochromis niloticus*. Journal of Fisheries and Aquatic Science 14: 238-243.

AL-DHABI NA & ARASU MV. 2016. Quantification of phytochemicals from commercial *Spirulina* products and their antioxidant activities. Evid. Based Complement. Altern. Med. 2016: 13p.

ALI SK & SALEH AM. 2012. *Spirulina* - an Overview. International Journal of Pharmacy and Pharmaceutical Sciences 4: 9-15.

AL-KENAWY D et al. 2008. Total replacement of fishmeal with soybean meal in diets for Nile tilapia in pre-fertilized ponds. *In*: ELGHOBASHY H et al. Cairo: Proceedings of 8th International Symposium on Tilapia in Aquaculture. p. 773-784.

AL-ZAYAT MA. 2019. Effect of various levels of *Spirulina* (*Arthrospira platensis*) as feed supplement on growth performance, feed utilization, immune response and hematology of the Nile tilapia (*Oreochromis niloticus*) fingerlings. Egyptian Journal of Aquatic Biology and Fisheries 23: 361-370.

AMADOU I et al. 2010a. Influence of *Lactobacillus plantarum* Lp6 fermentation on the functional properties of soybean protein meal. Emir. J. Food Agric. 22: 456-465.

AMADOU I et al. 2010b. Physicochemical and nutritional analysis of fermented soybean protein meal by *Lactobacillus plantarum* Lp6. World J. Dairy Food Sci. 5: 114-118.

AVNIMELECH Y. 1999. Carbon/nitrogen ratio as a control element in aquaculture systems. Aquaculture 176: 227–235.

AVNIMELECH Y. 2007. Feeding with microbial flocs by tilapia in minimal discharge bio-flocs technology ponds. Aquaculture 264: 140–147.

AVNIMELECH Y. 2009. Biofloc Technolog**:** a pratical guide book. 1.ed. Baton Rouge: World Aquaculture Society.

AVNIMELECH Y. 2011. Tilapia production using biofloc technology - saving water, waste recycling improves economics. Global Aquaculture Advocate 1: 66-68.

AVNIMELECH Y**.** 2015. Biofloc Technology: a practical guidebook, 3. d. Baton Rouge: World Aquaculture Society.

AWED E et al. 2020. *Spirulina platensis* Alleviated the Oxidative Damage in the Gills, Liver, and Kidney Organs of Nile Tilapia Intoxicated with Sodium Sulphate. Animals 10: 2423.

AZARM HM & LEE SM. 2012. Effects of partial substitution of dietary fish meal by fermented soybean meal on growth performance, amino acid and biochemical parameters of juvenile black sea bream *Acanthopagrus schlegeli*. Aquaculture Research 45: 994–1003.

AZIM ME & LITTLE DC. 2008. The biofloc technology (BFT) in indoor tanks: Water quality, biofloc composition, and growth and welfare of Nile tilapia (*Oreochromis niloticus*). Aquaculture 283: 29-35.

BABADZHANOV AS et al. 2004. Chemical Composition of *Spirulina Platensis* Cultivated in Uzbekistan. Chem. Nat. Compd. 40: 276–279.

BALAKRISHNAN K & PANDEY A. 1996. Production of Biologically Active Secondary Metabolites in Solid State Fermentation. Journal of Scientific and Industrial Research 55: 365-372.

BARBOSA AS et al. 2020. Economic analysis of family trout farming in Southern Brazil. Aquaculture International 28: 2111-2120.

BARNES M et al. 2015. Comparative performance of two rainbow trout strains fed fermented soybean meal. Aquaculture International, v. 23, n. 5, p. 1227–1238.

BATTAN B et al. 2006. High-level xylanase production by alkaliphilic *Bacillus pumilus* ASH under solid-state fermentation. World Journal of Microbiology and Biotechnology 22: 1281–1287.

BELAL EB et al. 2012. Use of *Spirulina* (*Arthrospira fusiformis*) for promoting growth of Nile Tilapia fingerlings. African Journal of Microbiology Research 6: 6423-6431.

BONALDO A et al. 2011. Increasing dietary plant proteins affects growth performance and ammonia excretion but not digestibility and gut histology in turbot (*Psetta maxima*) juveniles. Aquaculture 318: 101-108.

BORZANI W et al. 1999. A simple method to control the moisture content of the fermenting medium during laboratory-scale solid-state fermentation experiments. Braz. J. Chem. Eng. 16: 101-102.

BUHMANN AK et al. 2015. Optimization of culturing conditions and selection of species for the use of halophytes as biofilter for nutrient-rich saline water. Agricultural Water Management 149: 102–114.

BULBUL M et al. 2015. Effects of crystalline amino acids, phytase and fish soluble supplements in improving nutritive values of high plant protein based diets for kuruma shrimp, *Marsupenaeus japonicus.* Aquaculture 438: 98-104.

CAO S et al. 2018. Effects of dietary fishmeal replacement with *Spirulina platensis* on the growth, feed utilization, digestion and physiological parameters in juvenile gibel carp (*Carassis auratus gibelio var*. CAS III). Aquaculture Research 49: 1320-1328.

CAPELLI B & CYSEWSKI G. 2010. Potential Health Benefits of *Spirulina* Microalgae. Nutrafoods 9: 19–26.

CATALÁN N et al. 2017. Fermented Soybean Meal Increases Lactic Acid Bacteria in Gut Microbiota of Atlantic Salmon (*Salmo salar*). Probiotics and Antimicrobial Proteins 10: 566–576.

CHI CH & CHO SJ. 2016. Improvement of bioactivity of soybean meal by solid-state fermentation with *Bacillus amyloliquefaciens* versus *Lactobacillus* spp. and *Saccharomyces cerevisiae* LWT. Food Science and Technology 68: 619-625.

CHOI DG et al. 2019. Replacement of fish meal with two fermented soybean meals in diets for rainbow trout (*Oncorhynchus mykiss*). Aquaculture Nutrition 1: 1–10.

COLI AP et al. 2024. *Spirulina (Arthrospira platensis)* supplementation: Impact on growth, metabolism, and antioxidant status in zebrafish. J Anim Physiol Anim Nutr 2024: 1 – 14.

COLLA LM et al. 2004. Fatty acids profile of *Spirulina platensis* grown under different temperatures and nitrogen concentrations. Z Naturforsch 59: 55 – 59.

COSTA MLS et al. 2009. Efeitos De Diferentes Níveis Proteicos Da Ração No Crescimento Na Tilápia Do Nilo (*Oreochromis niloticus* Linnaeus, 1757), Variedade Chitralada, Criadas Em Tanques-Rede. B. Inst. Pesca 35: 285 – 294.

CRAB R et al. 2010. The application of bioflocs technology to protect brine shrimp (*Artemia franciscana*) from pathogenic *Vibrio harveyi*. J. Appl. Microbiol. 109: 1643–1649.

CRAB RT et al. 2012. Biofloc technology in aquaculture: Beneficial effects and future challenges. Aquaculture 356: 351-356.

DA SILVA MA et al. 2018. Crude protein levels in diets for two growth stages of Nile tilapia (*Oreochromis niloticus*) in a biofloc system. Aquaculture Research 49: 2693-2703.

DANIEL N. 2017. Status of aquaculture with respect to nutrition and feed. International Journal of Fisheries and Aquatic Studies 5: 333-345.

DANIEL N. 2018. A review on replacing fish meal in aqua feeds using plant protein sources. International Journal of Fisheries and Aquatic Studies 6: 164-179.

DAWOOD MAO & KOSHIO S. 2019. Application of fermentation strategy in aquafeed for sustainable aquaculture. Reviews in Aquaculture 12: 987–1002

DE LARA ANDRADE R et al. 2005. La importância de *Spirulina* em Ia alimentación acuícola. Contactos 57: 13-16.

DE OLIVEIRA N et al. 2022. Fermentation of Soybean Meal with *Lactobacillus acidophilus* Allows Greater Inclusion of Vegetable Protein in the Diet and Can Reduce *Vibrionacea* in the Intestine of the South American Catfish (*Rhamdia quelen*). Animals 12: 690.

EKASARI J. 2014. Biofloc technology as an integral approach to enhance production and ecological performance of aquaculture. Dissertation - Ghent University, Belgium.

EL BASUINI MF et al. 2016. Effect of different levels of dietary copper nanoparticles and copper sulfate on growth performance, blood biochemical profiles, antioxidant status and immune response of red sea bream (*Pagrus major*). Aquaculture 455: 32–40.

EL BASUINI MF et al. 2017. Effects of dietary copper nanoparticles and vitamin C supplementations on growth performance, immune response and stress resistance of red sea bream, *Pagrus major*. Aquaculture Nutrition 23: 1329–1340.

ELABD H et al. 2020. Nano *Spirulina* dietary supplementation augments growth, antioxidative and immunological reactions, digestion, and protection of Nile tilapia, *Oreochromis niloticu*s, against *Aeromonas veronii* and some physical stressors. Fish Physiology and Biochemistry 46: 2143-2155.

EL-DAHHAR AA & EL-SHAZLY K. 1993. Effect of essential amino acids (methionine and lysine) and treated oil in fish diet on growth performance and feed utilization of Nile tilapia. Aquaculture and Fishieries Management 24: 731-739.

ELÍAS JAL et al. 2015. Proximate composition of bioflocs in culture systems containing hybrid red tilapia fed diets with varying levels of vegetable meal inclusion. North American Journal of Aquaculture 77: 102-109.

EL-SAYD DMSD & GABER MMA. 2002. Complete Replacement of Fish Meal by Soybean Meal with Dietary L-Lysine Supplementation for Nile Tilapia *Oreochromis niloticus* (L.) Fingerlings. Journal of the World Aquaculture Society 33: 297–306.

EL-SHEEKH MI et al. 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 & Aquatic Sciences 14: 471–478.

EMERENCIANO MGC et al. 2012. Floc contribution on spawning performance of blue shrimp *Litopenaeus stylirostris*. Aquaculture 44: 75-85.

EMERENCIANO MGC et al. 2013. Biofloc Technology (BFT): A Review for Aquaculture Application and Animal Food Industry. In: Biomass Now - Cultivation and Utilization, Miodrag Darko Matovic, InTech.

EMERENCIANO MGC et al. 2017. Biofloc Technology (BFT): A Tool for Water Quality Management in Aquaculture. In: Water Quality, Hlanganani Tutu, InTech.

ERDOGAN F. 2019. Effects of *Spirulina platensis* as a feed additive on growth and coloration of blue dolphin cichlids (*Cyrtocara moorii Boulunger*, 1902). Aquaculture Research 50: 2326-2332.

FENG J et al. 2007a. Effects of *Aspergillus oryzae* fermented soybean meal on growth performance and plasma biochemical parameters in broilers. Anim. Feed Sci. Technol.134: 235-242.

FENG J et al. 2007b. The effect of *Aspergillus oryzae* fermented soybean meal on growth performance, digestibility of dietary components and activities of intestinal enzymes in weaned piglets. Anim. Feed Sci. Technol. 134: 295-303.

FERRARA E et al. 2015. Histological and micro-/macro-morphological evaluation of intestine in sharpsnout seabream (*Diplodus puntazzo*) fed soybean meal-based diets added with MOS and inulin as prebiotics. Aquaculture International 23: 1525-1537.

FAO. 2022. FOOD AND AGRICULTURE ORGANIZATION. The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome: FAO.

FAO. 2024. FOOD AND AGRICULTURE ORGANIZATION. The State of World Fisheries and Aquaculture 2024. Blue Transformation in action. Rome. Available in; https://www.fao.org/publications/home/fao-flagship-publications/the-state-of-world-fisheries-and-aquaculture. Access in 26 jun. 2024.

FRIAS JYS et al. 2008. Immunoreactivity and amino acid content of fermented soybean products. J. Agric. Food Chem. 56: 99-105.

FURUYA WM et al. 2005. Aplicação do conceito de proteína ideal para a redução dos níveis de proteína em dietas para a Tilápia do Nilo (*Oreochromis niloticus*). Revista Brasileira de Zootecnia 34: 1433-1441.

GLENCROSS B et al. 2011. Evaluating options for fish meal replacement in diets for juvenile barramundi (*Lates calcarifer*). Aquaculture Nutrition 17: 722-732.

GRASSI T et al. 2020. Growth performance and flesh quality of tilapia (*Oreochromis niloticus*) fed low concentrations of *Rubrivivax gelatinosus*, *Saccharomyces cerevisiae* and *Spirulina platensis*. Aquaculture International 28: 1305-1317.

GUTIÉRREZ-SALMEÁN G et al. 2015. Nutritional and toxicological aspects of *Spirulina* (*Arthrospira*). Nutr Hosp. 32: 34-40.

HA N et al. 2019. Sardine (*Sardinella* spp.) protein hydrolysate as growth promoter in South American catfish (*Rhamdia quelen*) feeding: Productive performance, digestive enzymes activity, morphometry and intestinal microbiology, Aquaculture 500: 99-106.

HABIB MD et al. 2008. A review on culture, production and use of *Spirulina* as food for humans and feeds for domestic animals and fish. Rome: Food and Agriculture Organization of the United Nations, Circular No. 1034.

HANSEN AC et al. 2011. Do plant-based diets for Atlantic cod (*Gadus morhua L.*) need additions of crystalline lysine or methionine? Aquaculture Nutrition 17: 362-371.

HARDY RW. 2010. Utilization of plant proteins in fish diets: effects of global demand and supplies of fishmeal. Aquaculture Research 41: 770-776.

HARGREAVES JA. 2006. Photosynthetic suspended-growth systems in aquaculture. Aquaculture Engineering 34: 344-363.

HASSAAN MS et al. 2018. Growth and physiological responses of Nile tilapia, *Oreochromis niloticus* fed dietary fermented sunflower meal inoculated with *Saccharomyces cerevisiae* and *Bacillus subtilis*. Aquaculture 495: 592-601.

HE M et al. 2020a. An evaluation of replacing fish meal with fermented soybean meal in the diets of largemouth bass (*Micropterus salmoides*): Growth, nutrition utilization and intestinal histology. Aquaculture Research 1: 1–13.

HE M et al. 2020b. Effects of fish meal replaced by fermented soybean meal on growth performance, intestinal histology and microbiota of largemouth bass (*Micropterus salmoides*). Aquaculture Nutrition 1: 1–14.

HENRIKSON R. 1995. Microalga *Spirulina*: superalimento del futuro. Barcelona: Ediciones Urano S.A.

HIRABAYASHI MT et al. 1998. Fermentation of soybean meal with *Aspergillus usamii* reduces phosphorus excretion in chicks. Poult. Sci. 77: 552-556.

HISANO H et al. 2019. Dietary protein reduction for Nile tilapia fingerlings reared in biofloc technology. Journal of the World Aquaculture Society 1: 1-11.

HONG K et al. 2004. *Aspergillus oryzae* fermentation improves nutritional quality of food soybeans and feed soybean meals. J. Med. Food, 7: 430-434.

HONG Y et al. 2021. The effects of replacing fish meal protein with a mixture of poultry by-product meal and fermented soybean meal on the growth performance and tissue nutritional composition of Asian seabass (*Lates calcarifer*). Aquaculture Research 52: 4105-4115.

HOSSAIN MS et al. 2016. Efficacy of nucleotide related products on growth, blood chemistry, oxidative stress and growth factor gene expression of juvenile red sea bream, *Pagrus major*. Aquaculture 464: 8–16.

HU Z et al. 2015. Effect of plant species on nitrogen recovery in aquaponics. Bioresource Technology 188: 92–98.

HUSSEIN EES et al. 2013. Enhancing the growth of Nile tilapia larvae/juveniles by replacing plant (gluten) protein with algae protein. Aquaculture Research 44: 937–949.

ILHAM I & FOTEDAR R. 2016. Growth, enzymatic glutathione peroxidase activity and biochemical status of juvenile barramundi (*Lates calcarifer*) fed dietary fermented soybean meal and organic selenium. Fish Physiology and Biochemistry 43: 775–790.

ILYAS A et al. 1995. A note on the removal of phytate in soybean meal using *Aspergillus usami*. Asian Australas. J. Anim. Sci, 8: 135-138.

JAKOBSEN GV et al. 2015. Improving the nutritional value of rapeseed cake and wheat dried destillers grains with solubles by addition of enzymes during liquid fermentation. Animal Feed Science and Technology 208: 198–213.

JANNATHULLA R et al. 2018. Effect of *Aspergillus niger* fermented soybean meal and sunflower oil cake on growth, carcass composition and haemolymph indices in *Penaeus vannamei* Boone, 1931. Aquaculture 486: 1–8.

JANNATHULLA R et al. 2019. Apparent digestibility coefficients of fungal fermented plant proteins in two different penaeid shrimps-A comparative study. Aquaculture Research 50: 1491–1500.

JIANG Y et al. 2018. Partial substitution of soybean meal with fermented soybean residue in diets for juvenile largemouth bass, *Micropterus salmoides*. Aquacult Nutr. 24: 1213–1222.

JU ZY et al. 2008. Determination of microbial community structures of shrimp floc cultures by biomarkers and analysis of floc amino acid profiles. Aquac. Res. 39: 118–133.

KADER MAS et al. 2011. Can fermented soybean meal and squid by-product blend be used as fishmeal replacements for Japanese flounder (*Paralichthys olivaceus*)? Aquac. Res. 43: 1427-1438.

KADER MAS et al. 2018. The use of fermented soybean meal and squid by-product blend as a substitute for fish meal in practical diets for climbing perch, *Anabas testudienus* (Bloch, 1792), pond culture: Growth performance and economics analysis. Journal of Applied Aquaculture 31: 1–21.

KISHIDA T et al. 2000. Soybean meal fermented by *Aspergillus awamori* increases the cytochrome p-450 content of the liver microsomes of mice. J. Agric. Food Chem. 48: 1367-1372.

LEE SM et al. 2016. Effects of dietary inclusion of fermented soybean meal on growth, body composition, antioxidant enzyme activity and disease resistance of rockfish (*Sebastes schlegeli*). Aquaculture 459: 110–116.

LEITE L et al. 2019. The use of *Arthrospira platensis* in rearing Nile tilapia (*Oreochromis niloticus*) in salt water. Ciência Agronômica 50: 593-599.

LI C et al. 2019. Beneficial influences of dietary *Aspergillus awamori* fermented soybean meal on oxidative homoeostasis and inflammatory response in turbot (*Scophthalmus maximus* L.). Fish & Shellfish Immunology 93: 8–16.

LI C et al. 2020. Effects of dietary raw or *Enterococcus faecium* fermented soybean meal on growth, antioxidant status, intestinal microbiota, morphology, and inflammatory responses in turbot (*Scophthalmus maximus* L.). Fish & Shellfish Immunology 100: 261-271.

LIANG X F et al. 2017. Substitution of fish meal by fermented soybean meal affects the growth performance and flesh quality of Japanese seabass (*Lateolabrax japonicus*). Animal Feed Science and Technology 229: 1–12.

LIMA CB et al. 2014. Fatores antinutricionais e processamento do grão de soja para alimentação animal. Agropecuária Científica do Semiárido 10: 24-33.

LIMA ECR et al. 2015. Cultivo da tilápia do Nilo *Oreochromis niloticus* em sistema de bioflocos com diferentes densidades de estocagem. Revista Brasileira de Saúde e Produção Animal 16: 948-957.

LIMA ECR et al. 2018. Culture of Nile tilapia in a biofloc system with different sources of carbon. Revista Ciência Agronômica 49: 458-466.

LIN S & LUO L. 2011. Effects of different levels of soybean meal inclusion in replacement for fish meal on growth, digestive enzymes and transaminase activities in practical diets for juvenile tilapia, *Oreochromis niloticus* × *O. aureus*. Animal Feed Science and Technology 168: 80–87.

LU MY et al. 1998. Application of a multilayer packed-bed reactor to citric acid production in solidstate fermentation using *Aspergillus niger*. Process Biochemistry 33: 117–123.

LUO G et al. 2014. Growth, digestive activity, welfare, and partial cost-effective ness of genetically improved farmed tilapia (*Oreochromis niloticus*) cultured in a recirculating aquaculture system and an indoor biofloc system. Aquaculture 422: 1-7.

MACIAS-SANCHO J et al. 2014. Fishmeal substitution with *Arthrospira* (*Spirulina platensis*) in a practical diet for *Litopenaeus vannamei*: effects on growth and immunological parameters. Aquaculture 426: 120-12.

MAHMOUD MMA et al. 2014. Effects of fish meal replacement with soybean meal and use of exogenous enzymes in diets of Nile tilapia (*Oreochromis niloticus*) on growth, feed utilization, histopathological changes and blood parameters. Life Science Journal 11: 6-18.

MAHMOUD M et al. 2019. The impact of several hydraulic fracking chemicals on Nile tilapia and evaluation of the protective effects of *Spirulina platensis*. Environmental Science and Pollution Research International 26: 19453-19467.

MAKKAR HPS. 1993. Antinutritional factors in foods for livestock. BSAP Occasional Publication 16: 69–85.

MANSOUR A et al. 2021. The Evaluation of *Arthrospira platensis* Bioactivity and their Dietary Supplementation to Nile Tilapia Vegetarian Diet on Growth Performance, Feed Utilization, Body Composition and Hemato-Biochemical Parameters. Annals of Animal Science 21: 1061-1080.

MARISCAL-LAGARDA MM et al. 2012. Integrated culture of white shrimp (*Litopenaeus vannamei*) and tomato (*Lycopersicon esculentum* Mill) with low salinity groundwater: Management and production. Aquaculture 366: 76–84.

MARTÍNEZ-CÓRDOVA LR et al. 2015. Microbial-based systems for aquaculture of fish and shrimp: A review. Rev. Aquac. 7: 131–148.

MASUMOTO T et al. 1996. Amino acid availability values for several protein souces for yellowtail (*Seriola quinqueradiata*). Aquaculture 146: 109-119.

MONIRUZZAMAN M et al. 2018. Evaluation of solid-state fermented protein concentrates as a fish meal replacer in the diets of juvenile rainbow trout, *Oncorhynchus mykiss*. Aquaculture Nutrition 24: 1198–1212.

MONROY-DOSTA MDC et al. 2013. Composición y abundancia de comunidades microbianas asociados al biofloc en un cultivo de tilapia. Revista De Biología Marina Y Oceanografía 48: 511–20.

MUKHERJEE R et al. 2015. Fermented soy products gaining popularity in poultry diets. All About Feed. 23: 22-23.

MUKHERJEE R et al. 2016. Role of fermentation in improving nutritional quality of soybean meal—a review. Asian-Australasian Journal of Animal Sciences 29: 1523-1529.

NAGAOKA S et al. 2005. A Novel Protein C-Phycocyanin Plays a Crucial Role in the Hypocholesterolemic Action of *Spirulina Platensis* Concentrate in Rats. J. Nutr. 135: 2425–2430.

NAYLOR RL et al. 2009. Feeding aquaculture in an era of finite resources. Proc. Natl. Acad. Sci. 106: 15103-15110.

NIBA AT et al. 2009. Bacterial fermentation in the gastrointestinal tract of non-ruminants: Influence of fermented feeds and fermentable carbohydrates. Tropical Animal Health and Production 41: 1393–1407.

NOVRIADI R et al. 2017. A meta-analysis approach toward fish meal replacement with fermented soybean meal: Effects on fish growth performance and feed conversion ratio. Asian Fisheries Science 30: 227– 244.

NOVRIADI R et al. 2018. Effects of soybean meal replacement with fermented soybean meal on growth, serum biochemistry and morphological condition of liver and distal intestine of Florida pompano *Trachinotus carolinus*. Aquacult Nutr. 24: 1066–1075.

NRC. 2011. National Research Council. Nutrient Requirement of Fish and Shrimps. Washington: National Academy Press.

ORIOL E et al. 1988a. Solid state culture of *Aspergillus niger* on support. Journal of Fermentation Technology 66: 57-62.

ORIOL E et al. 1988b. Water and water activity in the solid state fermentation of cassava starch by *Aspergillus niger*. Applied Microbiology and Biotechnology 27: 498-503.

PLAZA JLI et al. 2019. Effect of *Arthrospira* supplementation on *Oreochromis niloticus* gut microbiota and flesh quality, Aquaculture Research 50: 1448–1458.

PEIXE BR. 2024. Associação Brasileira de Piscicultura. Anuário Peixe BR de Piscicultura 2024. Available in: https://www.peixebr.com.br/anuario-2024/ Access in: 26 jun. 2024.

PICOLI F et al. 2022. Mixed culture microorganisms fermented soybean meal improves productive performance and intestinal health of Nile tilapia (*Oreochromis niloticus*) juveniles fed plant-based diets in a biofloc system. Aquaculture Research 53: 4233-4245.

PICOLI F et al. 2024. A biofloc system avoids the adverse effects of diets with suboptimal protein levels on zootechnical performance, intestinal histomorphometry, and protein metabolism of Nile tilapia juvenile fed *Spirulina* biomass (*Arthrospira platensis*) as an alternative protein source. Fish Physiol Biochem.

RAHIMNEJAD S et al. 2019. Replacement of fish meal with *Bacillus pumillus* SE5 and *Pseudozyma aphidis* ZR1 fermented soybean meal in diets for Japanese seabass (*Lateolabrax japonicus*). Fish & shellfish immunology 84: 987-997.

RAJI A et al. 2018. Fishmeal replacement with *Spirulina platensis* and *Chlorella vulgaris* in African catfish (*Clarias gariepinus*) diet: effect on antioxidant enzyme activities and haematological parameters. Res. Vet. Sci. 119: 67–75.

RAJI A et al. 2020. Dietary use of *Spirulina* (*Arthrospira*) and *Chlorella instead* of fish meal on growth and digestibility of nutrients, amino acids and fatty acids by African catfish. Journal of Applied Phycology 32: 1763-1770.

ROOHANI A et al. 2019. Effect of *Spirulina* (*Spirulina platensis)* as a complementary ingredient to reduce dietary fish meal on the growth performance, whole-body composition, fatty acid and amino acid profiles, and pigmentation of Caspian brown trout (*Salmo trutta caspius*) juveniles. Aquaculture Nutrition *25:* 633-645.

ROSENAU S et al. 2021. 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.

ROSS PR et al. 2002. *et al.* Preservation and fermentation: past, present and future. Int. J. Food Microbiol. 79: 3-16.

SALAH EL-DIN AE et al. 2021. Antioxidant capacity and DNA damage in Nile tilapia (*Oreochromis niloticus*) exposed to Ethidium bromide: A protective role for *Spirulina Platensis*. Scientific African 13: e00961.

SANJUKTA S & RAI A K. 2016. Production of bioactive peptides during soybean fermentation and their potential health benefits. Trends in Food Science & Technology 50: 1–10.

SEAN M et al. 2023. Composition and apparent digestibility coefficients of essential nutrients and energy of cyanobacterium meal produced from *Spirulina (Arthrospira platensis)* for freshwater-phase Atlantic salmon (*Salmo salar* L.) pre-smolts, Algal Research 70: 103017.

SHARAWY Z et al. 2016. Partial or total replacement of fish meal by solid state fermented soybean meal with *Saccharomyces cerevisiae* in diets for Indian prawn shrimp, *Fenneropenaeus indicus*, Postlarvae. Anim. Feed Sci. Tech. 212: 90–99.

SHARMA OP & SAINI VP. 2017. Replacement of fishmeal with soybean meal in Nile tilapia (*Oreochromis niloticus*) Diet. Journal of Entomology and Zoology Studies 5: 845-849.

SHIU YL et al. 2015. Using *Bacillus subtilis* E20-fermented soybean meal as replacement for fish meal in the diet of orangespotted grouper (*Epinephelus coioides*, Hamilton). Aquac. Res. 46: 1403–1416.

SINGH BP et al. 2014. Functional significance of bioactive peptides derived from soybean. Peptides 54: 171-179.

SIRAKOV I et al. 2012. The effect of meal (*Spirulina*) on the growth performance and carcass parameters of rainbow trout (*Oncorhynchus mykiss*). Journal BioScience Biotechnology 4: 151-156.

SOLIMAN H et al. 2021. Investigating the effects of copper sulfate and copper oxide nanoparticles in Nile tilapia (*Oreochromis niloticus*) using multiple biomarkers: The prophylactic role of *Spirulina*. Environmental Science and Pollution Research International 28: 30046-30057.

SØRENSEN M et al. 2009. Soybean meal improves the physical quality of extruded fish feed. Anim Feed Sci Technol. 149: 149–161.

SOTOUDEH E et al. 2016. Effect of Dietary Gamma-irradiated and Fermented Soybean Meal on the Growth Performance, Body Composition, and Digestive Enzymes Activity of Caspian Brown Trout, *Salmo trutta caspius*, Juvenile. Journal of the World Aquaculture Society 47: 830–842.

SUBRAMANIYAM R & VIMALA R. 2012. Solid state and submerged fermentation for the production of bioactive substances: a comparative study. International Journal of Science and Nature 3:480–486.

TACON AGJ et al. 2002. Effects of culture system on the nutrition and growth performance of Pacific white shrimp *Litopenaeus vannamei* (Boone) fed different diets. Aquacult Nutr. 8: 121–137.

TENG DM et al. 2012. Bio-modification of soybean meal with Bacillus subtilis or *Aspergillus oryzae*. Biocatal. Agric. Biotechnol. 1: 32-38.

THOMPSON FL et al. 2002. Importance of biofilm for water quality and nourishment in intensive shrimp culture. Aquaculture 203: 263-278.

TOKU SÖ & ÜNAL MK. 2003. Biomass Nutrient Profiles of Three Microalgae: *Spirulina Platensis*, *Chlorella Vulgaris*, and *Isochrisis Galbana*. J. Food Sci. 68: 1144–1148.

TURCHINI GM et al. 2019. Thoughts for the future of aquaculture nutrition: realigning perspectives to reflect contemporary issues related to judicious use of marine resources in aquafeeds. North American Journal of Aquaculture 81: 13–39.

UN 2021. United Nations. Department of Economic and Social Affairs Population Dynamics. World Population Prospects. (2019). Available in: https://population.un.org/wpp/Download/Standard/Population/ Access in: 15 jul. 2023.

VAN NGUYEN N et al. 2018. Utilization of fermented soybean meal for fishmeal substitution in diets of Pacific white shrimp (*Litopenaeus vannamei*). Aquacult Nutr. 24: 1092–1100.

VELASQUEZ S et al. 2015. Dietary *Spirulina* (*Arthrospira platensis*) replacement enhances performance of juvenile Nile tilapia (*Oreochromis niloticus*). Journal of Applied Phycology 28: 1023-1030.

WAHB MO & SANGAK Y. 2017. Enhancement of Reproductive Performance of Nile Tilapia *Oreochromis niloticus* using Phytobiotic *Spirulina platensis*. Journal of Biological Sciences 17: 305-311.

WANG L et al. 2016. Effects of soybean meal fermentation by *Lactobacillus plantarum* P8 on growth, immune responses, and intestinal morphology in juvenile turbot (*Scophthalmus maximus L.*). Aquaculture 464: 87–94.

WANG P et al. 2019. Effect of dietary fermented soybean meal on growth, intestinal morphology and microbiota in juvenile large yellow croaker, *Larimichthys crocea*. Aquaculture Research 50: 748–757.

WIDANARNI et al. 2012. Evaluation of biofloc technology application on water quality and production performance of red tilapia *Oreochromis* sp. cultured at different stocking densities. HAYATI Journal of Biosciences 19: 73-80.

WONGPUTTISIN P et al. 2007. Antioxidant activity improvement of soybean meal by microbial fermentation. Research Journal of Microbiology 2: 577-583.

WORLD BANK 2020. World Bank Commodities Price Data (The Pink Sheet). Available in: http://pubdocs.worldbank.org/en/895911554230066764/CMO-Pink-Sheet-April-2019.pdf. Access in: 02 abr. 2023.

WU GS et al. 2003. Effect of Substituting De-hulled or Fermented Soybean Meal for Fish Meal in Diets on Growth of Hybrid Tilapia, *Oreochromis niloticus*×*O. aureus*. Jornal da Sociedade de Pesca de Taiwan 30: 291-297.

WU L et al. 2012. Effect of wastewater C/N ratio on aerobic nitrifying sludge granulation and microbial population shift. Journal Environment Science 24: 234-241.

YAMAMOTO T et al. 2010. Influence of fermentation conditions for soybean meal in a non-fish meal diet on the growth performance and physiological condition of Rainbow trout *(Oncorhynchus mykiss)*. Aquaculture 309: 173-180.

YANG T et al. 2021. Advances in research on solid-state fermented feed and its utilization: the pioneer of private customization for intestinal microorganisms. Anim Nutr. 7: 905–916.

ZHANG H et al. 2016. Effects of dietary citric acid on growth performance, mineral status and intestinal digestive enzyme activities of large yellow croaker *Larimichthys crocea* (Richardson, 1846) fed high plant protein diets. Aquaculture 453: 147-153.

ZHANG W et al. 2021. Mechanisms by Which Fermented Soybean Meal and Soybean Meal Induced Enteritis in Marine Fish Juvenile Pearl Gentian Grouper. Frontiers in Physiology.

ZHANG W et al. 2024. Effects of partial replacement of fishmeal with *Spirulina platensis* powder and addition of *Spirulina platensis* polysaccharide on growth, nutrition, antioxidant capacity and gut microbiota of *Micropterus salmoides*, Aquaculture 586: 740802.

ZHAO P et al. 2012. The application of bioflocs technology in high-intensive, zero exchange farming systems of *Marsupenaeus japonicus*. Aquaculture 354: 97–106.

ZHUO LC et al. 2016. Apparent digestibility of soybean meal and *Lactobacillus* spp. fermented soybean meal in diets of grouper, *Epinephelus coioides*. Aquaculture Research 47: 1009–1012.